A COMPARISON OF THE PHYSIOLOGICAL AND THERMOREGULATORY RESPONSES OF CHILDREN AND ADULTS EXERCISING IN HOT ENVIRONMENTAL CONDITIONS

PETER LE ROSSIGNOL B.SC(ED). M.P.E.

Thesis for the award of Doctor of Philosophy

Department of Physical Education and Recreation
Victoria University of Technology
Footscray Campus, Victoria.

1992

DEDICATION

I dedicate this dissertation to my wife Susan and our three children David, Scott and Kara for their undying patience, continual support and sacrifices over many years of study.

ACKNOWLEDGEMENTS

I would like to thank my supervisor Dr John Carlson for his careful guidance and continual encouragement over the past five years. He has spent hundreds of hours discussing and planning the experiments and an equal amount of time reading and reviewing the manuscript. His efforts in gaining financial support from the Australian Sports Commission made the experimental work so much easier to complete. John has enthusiastically passed on his vast wealth of knowledge and has taught me the skills needed to complete a Doctor of Philosophy.

I would also like to thank Professor David Lawson for his advice, constructive comments and his part in helping me to become the first PhD student at Victoria University of Technology.

Geraldine Naughton was instrumental in making it possible to test students of the Ascot Vale Primary School. This was an essential and potentially difficult part of the study. I am therefore very much indebted to Geraldine for her assistance and support.

I would like to thank Ian Fairweather for the many hours of technical support that he gave generously. His competence in computer program development and his general assistance particularly when machinery failed, enabled the experiments to be successfully completed.

I would like to thank all the subjects who completed and participated in the study for their enthusiasm and dedication.

Professor Ken Hawkins deserves special thanks for assisting me in gaining time release to complete experimental work and for his personal encouragement to complete this Dissertation.

The figures were expertly designed by Brad Rhodes and for his time and advice I am very grateful. Also special thanks are extended to Ewen Wilson and Sheena Geysen for their skills in desktop publishing.

Thanks to all my colleagues at Ballarat University College for their helpful suggestions and continual encouragement.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

Table		Page

LIST OF FIGURES

Figure **Page**

Figure		Page

Figure **Page**

ABSTRACT

A COMPARISON OF THE PHYSIOLOGICAL AND THERMOREGULATORY RESPONSES OF CHILDREN AND ADULTS EXERCISING IN HOT ENVIRONMENTAL CONDITIONS

The purpose of this study was to examine the problem:
Do children have greater thermoregulatory and physiological limitations than adults to exercise in hot environmental conditions? Children and adults were compared in hot wet (T_a=31°C; RH=70%), and hot dry (T_a=35°C; RH=35%) and neutral (T_a=22°C; RH=50%) environmental conditions without radiant heat and also in hot wet environmental conditions with radiant heat (T_a=31°C; T_g=37°C and T_g=49°C; RH=70%). In all experiments the wind speed was maintained at 4m.sec^{-1}. The problem was examined by comparing core temperatures, skin temperatures, heart rate and sweat rates of children and adults exercising in the different hot environmental conditions.

In the first part of the study, children and adults exercised at approximately 50% VO_2 maximum for 30 minutes in each of neutral (T_a=22°C), hot wet (T_a=31°C, RH=70%) and hot dry (T_a=35°C, RH=35%) environmental conditions without radiant heat. The subjects were 16 physical education students (9 men and 7 women) with an average age of 21 years and 15 prepubertal children (8 boys and 7 girls) aged between 9 and 11 years. A large fan directed air at 4 m.sec^{-1} onto the anterior side of the subjects. The children were found in general to have a 6% lower metabolic efficiency than the adults. They also produced a more variable work rate both between the three environmental conditions and over time. The children used a 10% greater proportion of their heart rate reserve than the adults when both were exercising at 50% VO_2 maximum in neutral and hot wet environmental conditions. The children after 30 minutes of exercise in hot dry conditions increased their percentage of heart rate maximum to 17% above that recorded for the adults. In the hot wet conditions the male children produced 301 gm.hr^{-1} of sweat compared to the male adults who produced 877 gm.hr^{-1}. In the hot dry conditions the male children's sweat rate was 344 gm. hr^{-1} compared to the male adult rate of 1068 gm.hr^{-1}. The lesser relative sweat rates of these male children when they produced similar quantities of metabolic heat/kg as the male adults indicated that they did not need to sweat as much because they lost their heat convectively at a faster rate. The children had an initial 0.4 to 0.5°C higher core temperature than the adults measured in the ear canal, and this difference was maintained over the 30 minutes of exercise in the hot conditions. There were no obvious differences for mean skin temperatures between the groups. The differences between adults and children on the percentage of heart rate maximum and relative evaporation rates were eliminated when these dependent variables were covaried against the SA/mass ratio.

In the second part of the study, children and adults exercised for two 30 minutes sessions at approximately 50% VO_2 maximum in hot wet (T_a=31°C, RH=70%) environmental conditions while being exposed to either low (T_g=37°C) or high (T_g=49°C) levels of radiant heat. The subjects for this part of the study were

ten male physical education students with an average age of 23 years and ten male prepubertal children aged between 9 and 11 years. Both groups produced an equal metabolic heat stress of 7.3 $W.kg^{-1}$. There were no significant differences between the relative sweat rates of the children and the adults in both the low and high radiant heat conditions. The increased radiant heat gain of the children appears to have neutralized their greater convective heat loss when the radiant heat was applied to approximately 20% of the subjects' skin surface. The T_{ec} of the children's group was 0.3°C higher than the adult group and the mean skin temperature of the children's group was generally 1-2°C higher than the adults for both the skin exposed and that not exposed to radiant heat. These higher skin temperatures reflected the increased rate of convective heat loss of the children in comparison to the adults. The children exercised with a 6-7% higher percentage of heart rate maximum than the adults. When the SA/mass ratio was used as a covariate between children and adults it eliminated the differences between the groups for the percentage of heart rate maximum, core temperature and the skin temperatures not exposed to radiant heat.

In the third part of the study, the children and adults exercised for two 30 minute sessions at an increasing metabolic rate (38-64% VO_2 maximum) in hot wet environmental conditions while being exposed to either low or high levels of radiant heat. The subjects were the same as for part two of the study. In general the relative heat productions were proportionately matched by the relative sweat rates in both the low and high radiant conditions so that thermoequilibrium occurred. There were no significant differences between the children and the adults in the way that relative heat production was matched with relative sweat rates. The children were between 6-9% higher on the percentage of heart rate maximum compared to the adults throughout the 30 minutes of the increasing metabolism exercise test. At 30 minutes the children were exercising at 86% heart rate maximum and the adults were exercising at 79% of heart rate maximum. This result indicates that the children will experience cardiovascular limitations before adults when exercise intensities are increased towards maximal levels because they have a smaller heart rate reserve. The children had a 0.4°C higher core temperature than the adults and both groups increased their core temperature to the same extent when their exercise intensity was increased by similar percentages of VO_2 maximum. The children had 1-2°C higher mean skin temperatures than the adults for the areas exposed and those not exposed to radiant heat. An examination of the SA/mass ratios indicated that the children's size was a likely reason for the differences observed in thermoregulatory responses between the groups.

In conclusion, this study indicated that children exercising at the same relative intensity as adults in hot wet environmental conditions will have 0.3-0.4°C higher core temperatures and a 10% smaller cardiovascular reserve. Mean skin temperatures will also be 1-2°C higher for the children. This indicates that the children will lose heat convectively at a faster rate than adults and that they do not need to produce as much sweat/kg as the adults to reach thermoequilibrium. However, when radiant heat is applied to approximately 20% of the body's surface, the convective advantage of the children is neutralized by their radiative disadvantage. The above differences between children and adults do not indicate any relative disadvantage for reaching thermo-equilibrium. However, in hot dry conditions children will reach cardiovascular limiting conditions sooner than adults as they are operating with a much smaller cardiovascular reserve. The SA/mass ratio is the most likely reason for the above cardiovascular and thermoregulatory differences between children and adults.

CHAPTER ONE

INTRODUCTION

Children and adults often play sport in the hot dry and hot wet environmental conditions commonly experienced in Australia. Small percentages of the adult sporting population suffer heat related disorders competing in intense aerobic sports where metabolic and radiant heat loads are high (Haymes, 1984; Richards, 1987). These heat disorders include heat fatigue, heat syncope, heat cramps, heat exhaustion and heat stroke (Beyer, 1984). Children are considered to be more prone to these heat illnesses than adults because of the following physical and physiological characteristics (American Academy of Pediatrics, 1982).

1. Children have a higher surface area to mass ratio which means that they generally heat up at a faster rate than adults when exposed to very hot environmental conditions.
2. Children have a lower metabolic efficiency which produces a greater relative heat load at a set work rate.
3. Children have a reduced sweating capacity relative to their body surface area.
4. Children have a reduced capacity to convey heat from the body core to the skin.

In neutral (T_a=20-24°C) or warm environmental conditions (T_a=25-29°C) with a low relative humidity the characteristics mentioned in the previous paragraph do not interfere with the ability of the exercising child to adequately thermoregulate. However, in very hot conditions (T_a>36°C), when air temperature is above mean skin temperature, these characteristics become a disadvantage for children who heat up more quickly than adults and have less tolerance for exercise.

In hot environmental conditions (T_a=30-36°C) there is no conclusive evidence to suggest that exercising children are relatively more disadvantaged than exercising adults. So far, the majority of research comparing the thermoregulation of children and adults has typically been carried out in climate chambers under severe heat stress or neutral conditions. The findings of these studies have been extrapolated down to hot conditions and very broad recommendations made for children exercising in the heat. Furthermore, the conditions generally employed in climate chamber experiments have not accounted for two potentially significant heat stresses which occur in the natural environment, the wind and the sun. Wind velocity can theoretically advantage or disadvantage children exercising in the heat depending on the level of their mean skin temperature in comparison to the air temperature. If the air temperature is above the mean skin temperature of both children and adults, the children will gain heat, convectively faster than the adults. This pattern is reversed if the air temperature is below the mean skin temperature of both groups. Then convective heat will be lost at a faster rate by the children compared to the adults due to the children's larger surface area/mass. Higher wind velocities will accentuate this difference between adults and children by increasing the rate of convective heat exchange. The second of these, the effect of radiant heat on the thermoregulation of children, has not been researched.

In hot environmental conditions (T_a=30-36°C), the heat load on exercising humans is produced by solar radiation and metabolic heat. Humidity and air velocity affect the rate of heat loss. Increasing humidity reduces the potential for evaporative heat loss while increasing wind velocity increases the potential for both convective and evaporative heat loss.

There is a range of climates around Australia which produce hot stressful conditions. Traditionally they are classified into two major types: Hot Wet and Hot Dry.

In a hot dry climate, the main ingredients of environmental heat stress are a high air temperature and a high radiant heat load. Humidity is predominantly below 50%, and therefore the capacity of the body to cool itself by evaporation is not significantly retarded. These conditions occur in Perth during the Summer months where 8% of days exceed an air temperature of 36°C (Table 1). In these conditions children are disadvantaged because they have a higher surface area to mass ratio than adults. When the air temperature is above the mean skin temperature of the body (T_a>36°C) and solar radiation is high, children will heat up quicker than adults by the influx of both convective and radiant heat loads. During exercise these environmental heat loads might lead to exercise induced heat disorders earlier in children than adults. In hot dry climates when the air temperature is between 30-36°C the loss of convective heat from the body will be faster in children compared to adults. The high radiant heat load will continue to be a disadvantage for the children. These environmental temperatures are common in Perth with 27% of days (Table 1) producing these conditions during the summer months. In these hot conditions there is no conclusive evidence to suggest that either adults or children will be more disadvantaged than the other.

Table 1. Percentage of days exceeding potentially excessively hot conditions during Summer in two Australian cities.

City	Average global Radiation $mWh.cm^{-2}$	Relative Humidity %	Air Temperature °C	Days %
Perth	750	<50	>36	8
		<50	30-36	27
Darwin	600	>70	>30	22
		60-70	>30	31

$mWh.cm^{-2}$ = milliWatt hours per square centimeter.

In a hot wet climate humidity, wind velocity and a radiant heat load are the main ingredients of environmental heat stress. Increasing humidity reduces the ability of the body to cool itself by evaporation. Higher wind velocities increase the rate of evaporative heat loss. Radiant heat is less intense in hot wet climates than hot dry because the higher level of water vapour in the air absorbs a greater proportion of

the long infrared wave lengths (Blum,1945). In addition, air temperature is generally below skin temperature (Berger and Grivel,1989) which allows a significant amount of heat to be dissipated by convection and this effect is greater at higher wind velocities. The effect of solar radiation on the temperature of exposed skin surfaces has not been studied in detail.
Hot wet conditions frequently occur in Darwin during the Summer where 22% of days exceed both 30°C and 70% relative humidity (Table 1). As children have a higher surface area per mass ratio, they should absorb radiant heat faster but at the same time lose convective heat faster than adults. When a metabolic heat load produced by exercise is added to the radiant heat load it is unknown whether children or adults will heat up faster. Under these environmental conditions, if children do heat up more rapidly than adults they will be more likely to suffer heat disorders sooner during heavy exercise.

Further experiments are needed to explore the effect of varying metabolic and radiant heat loads to see if children are disadvantaged when exercising in these conditions. In particular the air temperatures examined should range between T_a = 30-36°C and the humidity should simulate either the hot dry or hot wet conditions which occur in Australia. These experiments should provide a theoretical basis to develop guidelines for children participating in sport in hot conditions.

STATEMENT OF THE PROBLEM

Do children have greater physiological and thermoregulatory limitations than adults when exercising in hot conditions?

The objectives of this study are:

1. To compare the effect of hot environmental temperatures and two levels of humidity on the physiological and thermoregulatory responses of children and adults. In this study the subjects exercised at 50% of VO_2 maximum for thirty minutes on a bicycle ergometer.
2. To compare the effect of different levels of radiant heat on the physiological and thermoregulatory responses of children and adults. In this study the subjects exercised at 50% of VO_2 maximum for 40 minutes in hot wet conditions on a bicycle ergometer.
3. To compare the combined effect of metabolic and radiant heat loads on the physiological and thermoregulatory responses of children and adults. In this study the radiant heat load was the same as for part 2 above but the work rate was increased each 10 minutes to produce easy, moderate and hard intensities. The subjects exercised for 30 minutes in hot wet conditions on a bicycle ergometer.

DELIMITATONS OF THE STUDY

The following restrictions were placed on the study.

1. This study was conducted on unacclimatized individuals who were involved in a moderate amount of activity. The subjects were recruited in Melbourne and were tested in the cooler months of the year. Findings of the study cannot be generalized to individuals living and participating in sport in hot climates.
2. This study was a comparison between prepubertal children aged from nine to twelve years and

young adults. The findings of the study cannot be generalized to younger children or older children who are in the pubertal growth spurt.

3. This study was conducted on a bicycle ergometer with a continuous constant level of exercise . As such the study's findings might not be able to be generalized to intermittent sporting activities.
4. The electric radiators used in the experiments have a different spectral signature than the solar heat load. The sun's spectrum produces radiant heat from visible light, the short infrared and the long infrared wavelengths while the radiators only produce heat from the long infrared wavelengths. While the quality of the radiant heat produced by the radiators is different to sunlight the quantity of radiant heat produced is similar to the amount arriving at the skin's surface in a tropical climate.
5. In Part A of the study, all subjects were tested in the neutral conditions first before performing either the hot wet or hot dry exercise tests in random order. The physiological effects due to habituation and performing the tests in a set order have not been controlled.

LIMITATIONS OF THE STUDY

The following shortcomings occurred in the study.

1. The ear canal temperature was used as a measure of core temperature. Although this was a suitable measurement it was not ideal as the thermistor probe could not be inserted into the ear canal to a constant depth. Pain on contact with the tympanic membrane precluded the adoption of this ideal site for the measurement of core temperature.
2. Subjects with less tolerance to exercise in hot conditions were less likely to volunteer for the study. This may have biased the sample towards children and adults who have a greater level of adaptability to exercise in hot conditions.
3. In the case of women subjects the stage of the menstrual cycle was not recorded.
4. The time of the day for the testing of the subjects was not controlled in the study.
5. The level of hydration was not controlled and could have a small effect on the thermoregulation of the subjects during a thirty minute exercise test in hot conditions.
6. The level of physical activity in the hours prior to the exercise tests was not controlled. Over the large sample size (N=51) and the multiple testing sessions this random factor was expected to have a minimal effect on the averaged results of the different groups.

DEFINITION OF TERMS

The symbols and definition of terms used in this study are:

T_a	Air Temperature measured by a dry bulb thermometer
T_w	Wet Bulb Temperature measured by a thermometer whose bulb is covered by cotton cloth saturated with water
T_g	Globe Temperature measured by a hollow copper 15cm diameter sphere blackened on the outside with a thermometer bulb at its center
T_s	Skin temperature
T_{snr}	Temperature of the skin not exposed to radiant heat
T_{ser}	Temperature of skin exposed to radiant heat
T_c	Core temperature
T_{rec}	Rectal temperature
T_{ty}	Tympanic membrane temperature
T_{ec}	Ear canal temperature
RH	Relative Humidity. It is the partial pressure of water vapour in the air divided by the saturated water vapour pressure at that temperature written as a percentage
V	Air velocity
WBGT	Wet Bulb Globe Temperature Index = $0.7T_w + 0.2T_g + 0.1T_a$
ET	Effective Temperature. ET is the temperature of still saturated air which gives rise to an equivalent sensation. It is found by a nomogram using T_a, T_w and V
CET	Corrected Effective Temperature is the same as the ET above but uses T_g instead of T_a
SA	Body surface area calculated by the Du Bois equation = $0.00178 \times WT^{0.425} \times HT^{0.725}$

SA/mass	Surface area per unit of mass $cm^2.kg^{-1}$
M	Rate of metabolic energy production (Watts)
W	Rate of work (Watts)
m	Mass (kg)
Ht	Height (cm)
ME	Metabolic efficiency; $ME = W/M$
H_p	Rate of heat production; $H_p = M - W$
S	Sweat rate measured by mass loss in $gms.hr^{-1}$
E	Evaporation rate measured by mass loss - respiratory mass loss - metabolic mass loss ($gms.hr^{-1}$)
E_h	Rate of evaporative heat loss (Watts)
h_e	Coefficient for evaporative heat loss
E_{max}	Maximal evaporative capacity of the environment
E_{req}	Amount of evaporation required to balance heat production and heat gain
$SHLI$	Sweat Heat Loss Index. This index is the sweat rate per rate of heat production. It measures the amount of sweat produced by the heat load due to exercise. It is used when a proportion of the sweat drips from the body.
$EHLI$	Evaporative Heat Loss Index. This index is the evaporative mass loss per rate of heat production. It measures the mass of sweat evaporated by the heat load due to exercise. It is used when the vast majority of the sweat is evaporated.
SE	Sweat efficiency measured by the evaporation rate/sweat rate
w	Wettedness measured by the evaporation rate/maximum evaporation rate
λ_s	Total heat of evaporation from the skin's surface

Φ_s	Relative humidity of the skin.
P_a	Water vapour pressure in the air (mm Hg)
P_s	Saturated water vapour pressure at the skin temperature (mmHg)
R	Rate of heat transfer by radiation (Watts)
h_r	Coefficient for radiant heat exchange
C	Rate of heat transfer by convection (Watts)
h_c	Coefficient for convective heat exchange
HRI	Heart rate index; the percentage of heart rate maximum divided by the percentage of maximum oxygen uptake
VO_2	Volume of oxygen uptake per minute

CHAPTER TWO

REVIEW OF LITERATURE

This chapter will establish the theoretical framework of the problem: Do children have greater thermoregulatory and physiological limitations than adults when exercising in hot conditions? The problem will be analysed in the context of the factors which affect thermoregulation (Figure 1). The different physical and physiological characteristics of children in comparison to adults are likely to express an equal quantity of heat stress as a different amount of heat strain.

Heat stress is due to environmental and metabolic heat loads on the subject and the reduction of these heat loads by environmental modifiers.

Heat strain is the response of the human body to the heat stress. Heat strain is determined by the human body's heat loss responses to a given heat stress and the subject's characteristics which modify these heat loss responses.

The following brief discussion relates the factors which affect human thermoregulation to the four major components of the model (Figure 1).

HEAT LOADS

The metabolic heat load is directly proportional to the rate of metabolic heat production which in turn depends primarily on the work rate. Adults with their larger body size and muscle mass work at higher rates and subsequently produce a greater amount of absolute metabolic heat than children. In order to compare the relative size of these metabolic heat loads, the absolute heat production of children and adults should be divided by their respective body masses.

Environmental heat loads are produced by the direct input of heat into the human body. These inputs occur via two physical mechanisms:

1. Convective heat gain occurs when the air temperature is above the mean skin temperature. The rate of heat gain depends on the size of the skin to air temperature gradient and the value of the convective coefficient.
2. Radiant heat gain occurs when the mean radiant temperature of the environment is above the mean skin temperature. The main factors which affect the rate of radiant heat gain are the temperature of the radiant heat source and the area of skin which is exposed to this source.

ENVIRONMENTAL MODIFIERS

Heat loss from the skin is modified by environmental variables:

1. As air temperature is increased towards the body's core temperature there is a decreased rate of convective heat loss due to the reduced skin to air temperature gradient.
2. As humidity is increased to high levels there is a decreased evaporative rate due to a decreased gradient of water vapour pressure between the skin and the air. Also a greater proportion of sweat drips off without evaporating.

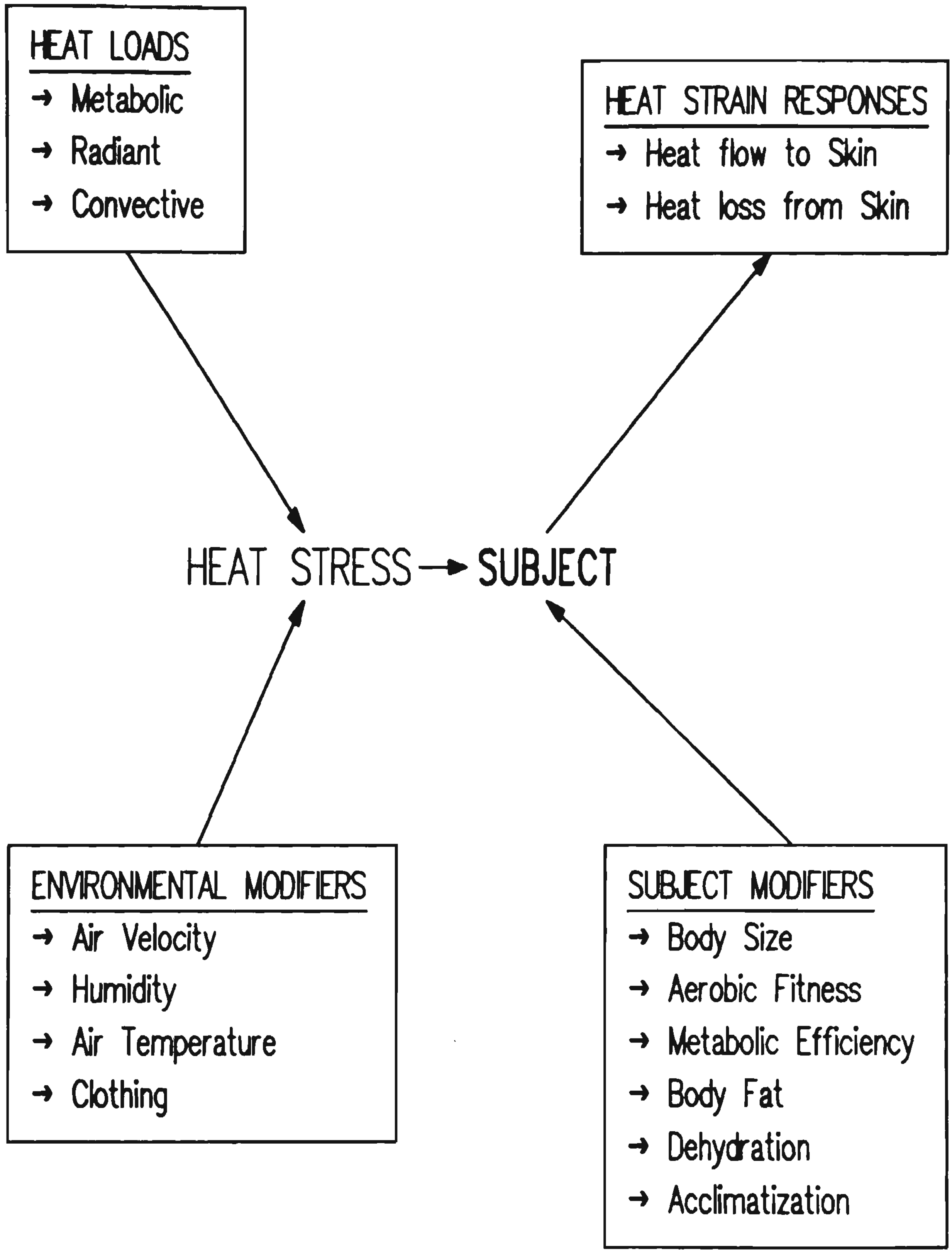


Figure 1. Model of factors affecting human thermoregulation

3. As wind velocities are increased the rates of both convective and evaporative heat losses are increased. Both the evaporation coefficient and the convection coefficient are equally affected by a change in wind speeds.

4. Clothing can have many different properties but it generally acts as a barrier to radiant heat entering the body and convective heat leaving the body.

SUBJECT MODIFIERS

Heat loss/gain responses are modified by the subject's characteristics.

The rate of the heat gain is affected by the subject's:

1. Percent fat: Fat has a lower specific heat and heats up faster than lean body tissue.
2. Metabolic efficiency: A less efficient subject will produce more metabolic heat at the same absolute workload than a more efficient subject.
3. Body size: A smaller subject will heat up faster than a larger subject in very hot conditions due to his/her greater surface area/mass ratio.
4. Level of dehydration: Dehydration causes greater increases in core temperature and heart rates as sweat and evaporation rates decline.

The rate of heat loss is affected by the subject's:

1. Acclimatization: Acclimatization produces a more efficient heat loss by increasing the sensitivity and amount of sweating which in turn decreases the core temperature and decreases the heart rate.
2. Aerobic fitness: A higher aerobic fitness increases the rate of heat loss because the resulting greater plasma volume is available for increased sweating and an increased cardiac output which delivers more heat-ladened blood to the skin.
3. Body size: A smaller individual loses heat faster than a larger individual by convection when the air temperature is below mean skin temperature due to the larger surface area/mass ratio.

HEAT STRAIN RESPONSES

Heat loss from the body involves two processes:

1. The transporting of the heat in the blood from the body's core to the skin.
2. The loss of heat from the skin's surface.

Heat transport to the skin is affected by the core to skin temperature gradient and the rate of skin blood flow. A larger core to skin temperature gradient and a greater skin blood flow both increase the rate of heat transfer. This process is controlled primarily by the central nervous system which integrates the sensing of core and surface temperatures. Increasing body temperature increases the neural drive for increasing skin blood flow. This response results in higher heart rates and a redistribution of blood from the visceral organs to the skin.

Heat loss from the skin is mainly affected by the skin to air temperature gradient and the evaporation of sweat. The body loses heat convectively in direct proportion to the skin to air temperature gradient and the rate of air movement over the skin's surface. An increasing body temperature increases the neural drive for sweating which increases the loss of body heat by the evaporation of water from the skin's surface. Evaporation is a finely tuned process which is initiated when the rate of convective heat loss cannot keep pace with the rate of body heat gain.

The following literature review is based on the above model. The topics will be similar to those in the model except for clothing, acclimatization and level of dehydration. While they are important as environmental modifiers of heat stress and subject modifiers of heat strain they are considered to be beyond the scope of this thesis.

METABOLIC HEAT

Gullestadt (1975) tested eleven year old boys at different metabolic heat loads in a comfortable environment (T_a = 22°C) and concluded that they regulate their body temperature during exercise in the same way as adults, however the children achieved thermal equilibrium sooner than adults. Thermal equilibrium occurred after 20-40 minutes of work in the children compared to 40-50 minutes of work in the adults. At 50% VO_2 maximum the boys attained a rectal temperature (T_{rec}) of 37.9°C. This compares closely with Saltin and Hermanson's (1966) adult subjects who reached a T_{rec} of 38.1°C at 50% VO_2 maximum. It was also found that the boys' sweat rate was directly proportional to the heat production as it is with adults and that the regression coefficients between sweat rate and heat production were not significantly different when the boys were compared to a study on adults (Nielson, 1969).

Conversely, Davies (1981) concluded that the thermal responses of children are quantitatively different to adults. He found that while exercising heavily (68% VO_2 maximum) in a comfortable environment (T_a=21°C) that the children dissipated approximately half their heat load by convection and radiation and half by the evaporation of sweat while the adults dissipated two thirds of their heat load by evaporation. The children had a higher skin temperature (+3°C) and lower sweat rates than their adult controls (Table 2). It was suggested that perhaps the children thermoregulate via the avenue which is most efficient for them. Thus, at moderate temperatures they use their relatively greater surface area to dissipate more of their heat by radiation and convection.

Table 2. Metabolic heat balance of adults and children exercising at 68% VO_2 maximum for 60 minutes

Subjects (n=16)	Metabolism $W.kg^{-1}$	Evaporation $W.kg^{-1}$	C&R* $W.kg^{-1}$	Storage $W.kg^{-1}$	Area/mass $cm^2.kg^{-1}$
Children	15.13	7.73	6.68	.71	335
Adults	16.12	10.47	5.32	.30	273
%Difference	+6.1	+26	-26		-23

Derived from Davies (1981) *C&R = Convection and Radiation

It seems that the children's 23% advantage in surface area/mass (Table 2) was closely related to their 26% greater use of convection and radiation to dissipate metabolic heat production. This preference does seem to have a cardiovascular cost with exercise heart rates being 26-38 beats higher in children compared to adults at 68% VO_2 maximum. Davies (1981) suggests that this limits the endurance capacity of children because a larger percentage of the children's cardiac output was taken up with the dissipation of metabolic heat from the skin. A limitation of the study was that the children produced 6% less metabolic heat than the adults and this difference compromises the comparison of their heat loss responses. This means that there was an unequal heat stress between the children and the adults; which was most likely a consequence of the lower aerobic fitness of the children.

In summary it appears that high metabolic heat loads generated by children in neutral conditions are suitably dissipated by the same mechanisms as adults but that the increased proportion lost via convection and radiation has a higher cardiovascular cost.

RADIANT HEAT

When exercising in hot conditions in a natural environment radiant heat adds significantly to the heat stress. Exercise induced heat exhaustion is a common occurrence in mass participation fun runs particularly when they occur in warm to hot conditions. High levels of radiant heat is considered to add significantly to the risk of heat exhaustion in individuals who are poorly acclimatized, dehydrated and relatively unfit (Richards and Richards, 1987). There are two main types of radiant heat which need to be defined because of their different effects on the skin (Buettner, 1951).

1. Non penetrating radiant heat: Long wave radiant heat which is absorbed by the upper surface of the skin e.g. a hot radiator. The radiant heat influx does not change with rising skin temperatures.
2. Penetrating radiant heat: Short wave radiant heat which is absorbed by the deeper layers of the skin e.g. the sun's radiation has long wave and short wave radiant heat which is absorbed at the skin's surface and by deeper layers of the skin.

The sun's spectrum has a maximum intensity at 0.5μ but it varies mainly between 0.29 and 2.2μ. As the sun's energy enters the atmosphere it is altered due to the unequal absorption of different wavelengths (Blum, 1945). Ozone absorbs radiation in the short ultraviolet end and water vapor absorbs radiation in the long infrared end. The least amount of absorption is when the sun is directly overhead and it gradually increases as the altitude of the sun increases. Table 3 indicates the amount of energy in different wavelengths of sunlight at different angles from zenith and different levels of water vapour pressure in the atmosphere. Twenty mm Hg of water vapour pressure reduces the amount of radiant heat by 10% compared to dry air. A 60° angle of the sun reduces the amount of radiant heat by 20% compared to directly overhead.

Table 3 Energy of Sunlight

Conditions	All Wavelengths $W.m^{-2}$	Visible light $W.m^{-2}$	Exclusive of visible $W.m^{-2}$
Dry air (0° zenith angle)	1026	418	607
Air: 20mm Hg H_2O (0° zenith angle)	921	412	509
Air: 20mm Hg H_2O (60° zenith angle)	740	328	412

Adapted from Blum (1945).

The amount of sunlight reaching the human body is mainly direct but it can also be reflected from the sky and the terrain. Typical amounts of radiant heat reaching a human at an angle of 60° from zenith in different climates is displayed in Table 4.

Table 4. Solar radiation flux in different climates

Terrain	Direct $W.m^{-2}$	Reflected by the sky $W.m^{-2}$	Reflected from terrain $W.m^{-2}$	TOTAL $W.m^{-2}$
Desert	1000	188	133	1321
Rain forest	840	180	46	1066
Tropical steppe	1020	114	105	1239

Roller and Goldman (1968).

The two hot dry climates represented by the desert and tropical steppe produce 24% and 16% greater intensity of radiation respectively; compared to the hot wet conditions represented by the rain forest climate. This is due predominantly to the greater absorption of the long infrared wavelengths by the high levels of water vapour evident in a hot wet climate.

Table 5 indicates the daily average global radiation which is incident on 10 Australian cities representative of both hot dry and hot wet climates in both summer and winter months. The first five cities represent hot dry climates and the second five cities represent hot wet climates. Radiant heat is a major factor contributing to heat stress. Global radiation as measured by the weather bureau indicates the average daily total amount of radiation for the month. Global radiation is the addition of direct radiation from the sun and diffuse radiation from the sky. It is generally measured on a flat horizontal plate which is protected from the wind, dust and humidity in the environment by a glass dome. These glass domes allow short wave radiation (0.3 to 3 microns) to reach the detecting surface. This is generally the majority of the energy which is delivered by the sun. The units for global radiation are milliwatt hours per cm^2 which is the total amount of radiant heat delivered to a 1 cm^2 flat surface in daylight hours. These values have been converted to $W.m^{-2}$ for five of the cities so that radiation averaged over a whole day can be compared to the directly measured radiation intensity occurring in the different terrains referred to in Table 4. The average daily values give very little information on the actual radiation intensity measured during the hottest part of the day. Roller and Goldman (1968) indicate that radiation intensities of up to twice these average values often occur in the hottest part of a summer day.

Table 5. Average Global Radiation for ten Australian cities

	January Daily Average		July Daily Average	
Cities	$mWhr.cm^{-2}$	($W.m^{-2}$)	$mWhr.cm^{-2}$	($W.m^{-2}$)
Adelaide	700		200	
Perth	750	536	250	234
Melbourne	700	483	200	205
Broken Hill	800		300	
Alice Springs	800		400	
Darwin	600	470	500	435
Townsville	600		450	
Brisbane	650	474	350	333
Coffs Harbour	650		300	
Sydney	650	459	300	297

When air temperatures exceed 36°C the only avenue of heat loss is evaporation. Exposed to these conditions children should be under an added disadvantage as their greater SA/mass ratio enables them to absorb both radiant and convective heat at a faster rate than adults. In fact radiant heat at lower air temperatures than 36°C could place children at a thermoregulatory disadvantage as they will absorb the radiant heat faster than adults.

The incident radiation is not all absorbed by the skin's surface. Martin estimates that 43% of sunlight is reflected from blonde skin and 35% is reflected from brunette skin. Kerslake (1972) estimates that 40% of the sun's radiant energy is reflected by white skin while only 20% of the radiant energy is reflected from negro skin. Also the amount of radiant energy absorbed by the skin is proportional to the area of skin facing the sun (direct) or facing the sky and terrain (indirect). The projected radiation as a proportion of the total skin area varies between 5% (sun overhead) to 25% (facing the sun with sun's altitude at 90°). When the sun's altitude is at 60° from zenith and the subject is standing side on about 22% of the skin's surface area is exposed to the radiant heat (Kerslake,1972).

Table 6. Solar heat load absorbed by an adult person standing erect with the sun at different altitudes.

Zenith angle	Direct *W.*	Sky *W.*	Terrain *W.*	TOTAL *W.*
0°	63	79	131	273
60°	186	31	52	269

Adapted from Blum (1945).

From Table 6 it can be seen that while direct solar radiation is lower at midday greater amounts of sky and terrain radiation impinge on the skin. At 4.00 PM with the sun 60° from zenith the diffuse radiation is much reduced but the direct sun radiation is three times greater, producing similar amounts of total radiant heat impinging on the human body. This extra heat load of about 270 Watts is for a temperate summer climate with 20mm Hg of water vapour pressure (Blum, 1945). This assumes a nude white subject. Obviously different colours and types of clothing will change the percentage of radiant heat that is reflected. If the subject was to wear white clothing the extra reflectance would reduce the absorption of radiant heat while dark clothing would increase the absorption of radiant heat. Children with their smaller surface area would proportionally absorb less radiant heat e.g. $1.1m^2$ would mean 165 watts of radiant heat. If this absorbed radiant heat is converted to a radiant heat load per kg, the childrens relative radiant heat load of $165/32 = 5.2W.kg^{-1}$ is considerably more than the adults relative heat load of $270/69 = 3.9W.kg^{-1}$. This means that the children have a 33% greater radiant heat stress because of their larger SA/mass ratio. The anthropometric data used in the above calculations was taken from Tanner's (1978) average height and weight data for 10 year old and eighteen year old males. Kerslake (1972) has calculated a similar radiant heat balance sheet to Blum (1945) but for clothed subjects marching in the desert and he estimated a radiant heat gain of 400 watts. This can be considered the upper limit of radiant heat loads on humans as the desert is the most stressful of naturally occuring radiant heat environments. This heat load is 66% greater than that calculated by Blum (1945) and represents a radiant heat load of 7.8 $W.kg^{-1}$ for average ten year old children and $5.8W.kg^{-1}$ for average adults. Kerslake's (1972) data indicates that about 17% of the total radiant heat measured in the desert environment is absorbed by an erect walking adult.

Nielson (1988) who studied ten male subjects exercising at 92 watts on a bicycle ergometer suspended on a balance in shade and sun in Copenhagen found that the average heat load from the sun was 100 watts. The air temperature over the time period varied between 21°C and 25°C. The extra heat load was dissipated by an increased sweat loss of $145gm.hr^{-1}$. The other avenues of heat loss calculated by partitional calorimetry methods stayed close to constant. Nielson concluded that this solar heat load measured in a temperate climate is a significant addition to heat stress when adults are exercising at maximal metabolic rates. The projected radiant area on the skin varied between 10 and 20% of the total body surface area at this latitude. Children with their greater SA/mass ratio will proportionally have a greater heat load produced by this level of solar radiation.

Kamon et al (1983) studied the heart rate response to increases in air temperature, water vapour pressure and radiant heat. These three environmental stresses increase heart rate due to a need to increase heat transport to the periphery. The heart rate response for each 1°C increase in T_g above T_a was an increase of 0.8 bt. min^{-1}. This is just below the effect of each 1°C rise in T_a above 25°C which increases heart rate by 1 bt. min^{-1}. The effect of increasing water vapour pressure by 1mm Hg above 13mm Hg is to increase the heart rate by 1 bt. min^{-1}. It can be hypothesized that children will have greater increases in heart rate than adults with increasing levels of radiant heat.

Ratogi (1989) has reported that twelve year old Indian children working in a glass bangle factory were under high radiant heat loads for the 10-12 hours of their shift. He measured the average globe temperature to be 46°C; 8°C above the mean dry bulb temperature of 38°C. The WBGT index was 34.4°C and the effective temperature was 34.3°C. He found that these children's oral temperature increased by 0.9°C to 37.5°C during the shift while those children not exposed to radiant heat increased by 0.4°C. Heart rates of the Indian children averaged 112 bts.min^{-1} by the end of the shift and those children not exposed to radiant heat averaged 90 bts. min^{-1}. These physiological responses are close to the maximal that can be tolerated by adults for long shifts with core temperatures just below the accepted maximum of 38°C and heart rates just above the accepted maximum of 110 beats per minute (Kamon, 1983).

CONVECTIVE HEAT

In very hot environmental conditions, in particular air temperatures over 36°C, the relatively larger surface area of children is a disadvantage as children absorb heat faster by convection than adults (Haymes, 1984). To maintain thermoregulation, shell temperatures need to be 1.2°C below core temperatures (Wells, 1980). This difference cannot be maintained solely by convective heat loss when T_a>36°C; therefore it is appropriate to define this as the arbitrary border between hot and very hot environmental conditions. Drinkwater and Horvath (1979), testing young girls in a hot dry climate (T_a = 48°C) found that they had less tolerance to this heat than adults, and related this to an inadequate cardiovascular response. The lower stroke index (ml.$beat^{-1}$.m^{-2}) at rest and a higher percentage of the maximum heart rate while walking (25 -30% VO_2 maximum) in the very hot environment both indicated a greater pooling of blood in the periphery of the children, with a smaller percentage of the total blood volume being used for muscle metabolism.

Alternatively, the American Academy of Pediatrics (1982) claimed that children thermoregulate less efficiently than adults because they have a reduced sweating capacity. Inbar(1978) exercising 8-10 year old boys in air temperatures of 43°C found that they had a 48% lower sweat rate per unit area than adults. This fact does not indicate the realistic situation as the amount of evaporation depends on the amount of metabolic heat produced. As heat fills a volume, in order to compare children and adults; the amount of metabolic heat produced must be measured relative to body mass ($W.kg^{-1}$). Inbar's 1978 study equated all groups to be working at 85% of heart rate maximum but the children and adult groups happened to be exercising at different percentages of VO_2 maximum and also producing different amounts of metabolic heat .

Table 7. Heat exchange of children and adults when exercising for 60 minutes at T_a=43°C.

Group	Age yrs	n	Metabolism W.kg⁻¹	Radiation & Convection W.kg⁻¹	Evaporation W.kg⁻¹	Storage W.kg⁻¹
Children (W)	9	8	7.58	1.48	6.85	2.22
Children (H)	9	8	7.45	2.37	7.67	2.15
Children (WH)	9	9	8.43	2.30	7.87	2.31
Children (C)	9	7	9.64	0.29	8.16	1.93
Adults (WH)	22	9	9.79	1.29	7.94	2.57
Adults (C)	22	7	9.44	1.43	8.00	2.59

Adapted from Inbar (1978)

W = Work Group WH = Work in heat study

H = Heat Group C = Control Group

Table 7 indicates that the children were generally producing relatively less metabolic heat than the adults, and therefore they didn't need as much evaporation to dissipate this heat. In the one instance where a children's group approached the metabolic heat production of the adults, this group also had a higher evaporative rate than the adult groups. As storage and heat gain by R&C are small components of the heat exchange equation it seems that there is an effective balance between metabolism and evaporation both in children and adults under these conditions. Since R&C is calculated by difference from the other values in the heat exchange equation it has a greater error and is largely a rough approximation of the true value. While it appears that the children's groups ($\bar{X}$ =1.61) absorb more radiative and convective heat than the adult groups ($\bar{X}$=1.36), the children's groups also vary from less to more convective heat gain than the adult groups. To fully evaluate the significance of the *R&C* term, the errors involved in the other terms of the heat exchange equation should be assessed.

Wagner (1972) compared the heat exchange of adult men and pre and post pubertal children in 49°C heat as they walked on a treadmill at 5.6 $Km.hr^{-1}$ for 40-90 minutes (Table 8). Table 8 indicates that children produced more metabolic heat and absorbed more heat by radiation and convection probably due to their larger surface area/mass ratio, but they compensated by a greater evaporative rate and more storage. The children were not in thermal equilibrium and were continuously increasing T_{rec} over time as more heat was stored in their bodies. An appropriate conclusion for the above research is that children have limited thermoregulatory abilities when exercising at the same absolute workloads as adults because they have reached maximal evaporative rates whilst the adults achieved thermoequilibrium at lower evaporative rates. The limitations of this study were the unequal metabolic heat production and the lack of equalization of physiological stress. To equalize the physiological stress the three groups needed to be exercising at the same percentage of VO_2maximum.

Table 8. Heat exchange of children and adults when exercising for 40-90 minutes in 49°C heat.

Group	n	Age yrs	Metabolism $W.kg^{-1}$	Radiation& Convection $W.kg^{-1}$	Storage $W.kg^{-1}$	Evaporation $W.kg^{-1}$
Pre-pubertal boys	5	11-14	6.32	6.06	1.60	10.93
Post-pubertal boys	5	15-16	6.82	6.36	1.35	11.74
Young men	5	25-30	5.58	5.62	1.26	9.96

Adapted from Wagner (1972).

Australia has climatic conditions where T_a is often above mean skin temperatures. These are demonstrated in Table 9, where five Australian cities have a hot dry summer. A ten year analysis of dry bulb temperatures (T_a) and wet bulb temperatures (T_w) from figures supplied by the Bureau of Meteorology between 1973 and 1982 has established the percentage of days between 30-36°C and also those greater than 36°C. Perth has 10% and Broken Hill has 16% of days over 36°C during January and February.

Table 9. Percentage of days with temperatures greater than 30°C .

	November		December		January		February		March	
Air temp Cities	30-36	>36	30-36	>36	30-36	>36	30-36	>36	30-36	>36
Adelaide	10	1	15	5	15	8	14	5	12	1
Perth	9	1	17	5	28	11	37	9	26	3
Melbourne	6	1	11	2	15	5	12	5	10	0
Broken Hill	23	2	34	10	32	15	38	17	32	1
Alice Springs	49	22	49	37	45	36	49	26	59	10

In hot dry climatic conditions with T_a > 36°C the water vapour pressure is generally less than 1.7KPa (13mmHg) which means that humidity has a minimal effect on thermoregulatory and cardiovascular responses. i.e. evaporation occurs readily and is effective for cooling. Kamon (1983) expects heart rates to be raised by 1 beat.min^{-1} for each 1°C that the dry bulb is above 25°C. i.e. for T_a = 36°C heart rate is raised by 11 beats.min^{-1}.

To summarize, the sections on metabolic and convective heat have demonstrated that children either absorb or lose more convective heat than adults depending on air temperatures being above or below the mean skin temperature respectively.

HUMIDITY

In hot wet climates the effect of global radiation becomes less intense as the values are substantially lower than for a hot dry climate (Tables 3&4). Instead, relative humidity becomes critical with higher humidities reducing the efficiency of sweating. Increased amounts of sweat drips from the body without evaporating with its cooling function being lost. This effect is reduced by increasing wind speeds which substantially increase the evaporation of sweat from the body. Some heat can also be lost by convection particularly when the mean skin temperature is above air temperature, which is usually the case in hot wet climates. Adults with their lower surface area to mass ratios would lose less heat by this means than children. Thus heavy exercise might be more dangerous for adults than children when T_a is between 30°C and 36°C with the humidity in excess of 70%. Townsville averages 14% and Darwin averages 22% of days with these conditions over the Summer months (Table 10).

Table 10. Percentage of days exceeding 60% relative humidity with air temperatures also greater than 30°C.

	November		December		January		February		March	
%RH	>70	60-70	>70	60-70	>70	60-70	>70	60-70	>70	60-70
Cities										
Darwin	9	42	16	45	22	24	28	24	26	25
Townsville	2	16	9	27	12	31	21	24	8	20
Brisbane	0	1	1	8	1	7	2	6	0	3
Coffs Harbour	0	0	0	1	0	0	0	0	0	0
Sydney	0	0	0	0	0	1	0	1	0	0

Wallerston and Holmer (1984) have looked at efficiency of sweating (SE) when exercising in environments with increasing humidity.

$$SE = \frac{\text{Sweat Evaporation Rate}}{\text{Total Sweat Rate}} \times 100$$

Their subjects worked at a metabolism of 100W, an air temperature of 36°C and an air velocity (V) below $0.2 m.sec^{-1}$. In these conditions heat gain or loss by convection is minimal and the metabolic heat load has to be mainly dissipated by the evaporation of sweat. Table 11 demonstrates that sweating efficiency decreases as humidity is increased. Table 11 also demonstrates that there is an effective heat loss up until 70% relative humidity where wettedness equals 1.0. Wettedness (w) is the actual evaporation divided by the total evaporation possible under the prevailing environmental conditions. When w equals 1.0 there is no further potential for increasing heat loss through evaporation. At 30% and 50% relative humidity, evaporation is effective at removing the metabolic heat produced. At 70% relative humidity not all of the metabolic heat is removed. i.e. 8.6/10.7 = 80% of the previous amount is removed. The result is that the core temperature increases as metabolic heat is stored at a faster rate in the body with a subsequent increase in T_s. The rise in T_s increases the vapour pressure difference between the skin and the air and consequently increases the potential for evaporation. Wallerston and Holmer (1984) found that sweat efficiency of the exercising subjects was 100% when wettedness was less than 0.18. When the work rate was increased from 50W to 125W at 50% relative humidity, sweat efficiency decreased from 83% to 58%. It appears that exercise increases the drive to sweat which removes metabolic heat from the body but in the process there is a lower sweat efficiency under the same environmental conditions.

Table 11. Mean values of the thermoregulatory variables measured on six subjects working at 100W in T_a = 36°C.

Relative Humidity Variables	30%	50%	70%
T_s °C	36.6	36.4	37.6
T_{rec} °C	37.7	37.7	38.3
VO_2 $l.min^{-1}$	1.58	1.58	1.60
Total sweat rate $g.min^{-1}$	13.7	15.5	19.1
Drip sweat rate $g.min^{-1}$	3.0	4.8	10.5
Evaporation rate $g.min^{-1}$	10.7	10.7	8.6
Sweat efficiency %	79.0	68.0	48.0
Wettedness	0.54	0.72	1.0

Wallerston and Holmer (1984).

If children do sweat less than adults at the same metabolic heat production it is also important to determine their sweating efficiency. Children can be expected to have a greater sweating efficiency (E/S) than adults because their evaporation coefficient (h_e) is expected to be larger because of their smaller size. Children could still lose as much heat by evaporation as adults but sweat less. The rate of evaporation depends on h_e and the vapour pressure difference between the skin and the air, i.e. $E = h_e(\phi_s.P_s - P_a)$ where ϕ_s is the relative humidity of the skin. According to Kerslake (1972) who has undertaken extensive research in this area the general formulae for h_e = 15 x h_c. Also $h_c = BV^n$ where *B* is an experimentally determined coefficient and *V* is the average air velocity past the subject. Kerslake's best estimate of h_c for standing man is $h_e = 7.2V^{0.6}$. Consequently $h_e = 108V^{0.6}$. H_e has not been established experimentally for children with their substantially different size in comparison to adults. H_c has been established experimentally for a Vernon globe (Diameter 15cm). H_c for a Vernon globe = $14V^{0.6}$ where V is equal to wind velocity. H_c for black globes of different diameters can be established using the more general relationship (Kerslake 1972). i.e. H_c globe = $14V^{0.6} \times L^{-0.4}$ where *L* is considered to be the characteristic dimension. i.e. diameter of the globe. When the globes diameter was halved the new h_c increased by 32%. Assuming that the same approach can be used for calculating h_c for children; the average 10 year old boy (Tanner, 1978) is 138cm tall and the average adult is 176cm tall. This means that the ten year old child's characteristic dimension (Height) is 78% of the adult size.

$$h_c = 7.2V^{0.6} \times L^{-0.4} \quad (L = 0.78)$$
$$= 7.95V^{0.6}$$

Thus ten year old children's theoretical h_c is increased by 10% in comparison to the adult's. It also follows that the children's h_e will be 10% greater than the adult's. This means that the children's evaporative heat loss can be similar to the adult's but with a lower sweat production. As E_{max} increases *W* will also decrease, i.e. $W = E/E_{max}$. When *W* decreases *SE* increases (Table 12). Thus the children are theoretically more efficient at losing heat and have a higher sweating efficiency than adults.

Children can also be more efficient sweaters for a second reason. In air temperatures below mean skin temperatures children will lose heat convectively faster than adults due to their larger SA/mass ratio. They therefore don't need to sweat as much as adults to dissipate the same relative metabolic heat load. As the need for sweating decreases *W* also decreases. i.e. $S = W/SE \times E_{max}$. This means that their wettedness (E/E_{max}) will be lower than the adult value. Also as *W* decreases *SE* increases (Table 12). This argument indicates that children will again have a higher sweating efficiency than adults.

Table 12. Values of sweating efficiency at various values of wettedness for a uniformally sweating cylinder in a transverse wind.

Wettedness (= E/E_{max})	1.0	0.9	0.8	0.7	0.6	0.5	0.45
Sweating efficiency (= E/S)	0.60	0.73	0.82	0.89	0.94	0.98	1.00

Kerslake (1972)

Wallerston and Holmer (1984) have demonstrated a similar inverse relationship between *W* and *SE* for exercising adults but the relationship is quantified differently as shown by Figure 2.

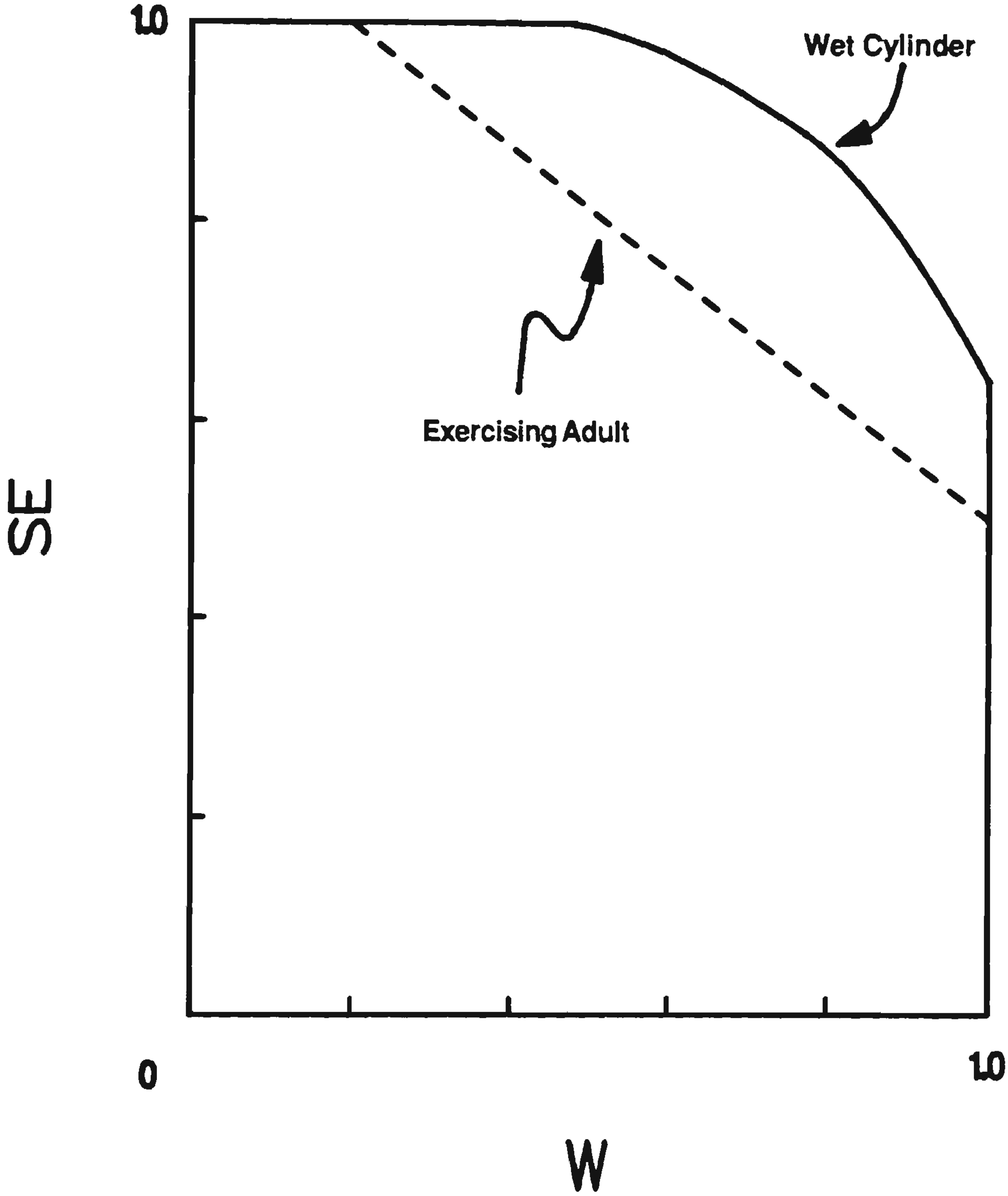


Figure 2 Relationship between sweating efficiency and wettedness for an exercising adult and a cylinder in a wind. (Adapted from Kerslake, 1972 and Wallerston and Homer, 1984)

Figure 2 demonstrates that the cylinder has a different relationship between W and SE compared to exercising adults. Children should have a different line again demonstrating a higher sweat efficiency at the same wettedness since they theoretically have a higher h_e. Frye and Kamon (1983) who exercised acclimatized men and women in humid heat T_a/T_w = 37°C/30°C at 30% of VO_2maximum found that the women had a higher SE than the men while the men had a higher w than the women (Table 13). The wettedness values and sweat efficiencies have been calculated in thermal equilibrium. Since the E_{max} is 10% higher for women and the environmental conditions are the same, h_e for the women must be considered to be greater than the h_e of the men. It is the women's smaller body dimensions which enables them to sweat more efficiently than men. Children can be expected to be affected in a similar way and also have a greater sweating efficiency than adults.

Table 13. Wettedness and sweat efficiency in men and women exercising in a humid environment.

Sex	E_{max} $W.m^{-2}$	W	SE	SA/mass $cm^2.kg^{-1}$
Men	206.7	0.99	0.81	256.5
Women	226.7	0.90	0.99	282.7

Frye and Kamon (1983).

Candas (1982) who compared unacclimatized men and women at rest in humid heat found that they both had the same equilibrium evaporation rate ($150g.hr^{-1}.m^{-2}$) but the men had a higher sweat rate and a lower sweating efficiency until hidromeiosis slowed the drippage rate after the first hour of exercise and increased the men's sweating efficiency. The likely explanation for the women's greater sweat efficiency is their greater h_e and greater convective heat loss, both of which are related to their smaller body size.

Table 14 demonstrates the effect of increasing humidity at different air temperatures on the calculation of E_{max} for adults and children. The ten year old children were considered to be 78% of the adult's height and the theoretically calculated h_e was 10% greater at both air velocities. The skin temperatures were calculated to be between 34°C and 35°C by the Berger and Grivel formulae (1989).

Table 14 indicates that E_{max} decreases with increasing humidities and with increasing air temperatures. At high humidities and high air temperatures evaporation can become limiting if metabolic heat production is above E_{max}. Ten year old children have a theoretically 10% greater evaporative capacity compared to adults in these air temperatures and humidities.

Table 14. E_{max} * for children and adults at increasing humidities and different air temperatures

Relative Humidity	70%			80%			90%		
Wind speed	1 m.sec⁻¹		4 m.sec⁻¹	1 m.sec⁻¹		4 m.sec⁻¹	1 m.sec⁻¹		4 m.sec⁻¹
Status	A	C	A	A	C	A	A	C	A
Air temperature									
28°C	342	375	684	295	324	590	248	272	496
30°C	314	345	628	261	287	522	209	229	418
32°C	282	310	564	223	245	446	164	180	328
34°C	245	369	470	179	197	358	113	124	226

A = adult C = child

* Units of E_{max} are $W.m^{-2}$

The evaporative heat loss E is equal to mλ where λ is the latent heat of vaporization and m is the evaporative mass loss. λ is close to being a constant with a 1% variation in values for skin temperatures between 30°C and 38°C. The assumption in the calculation of E is that the skin is covered by a continuous film of water. This rarely occurs in practice and increases the variation in the value of λ by a further 10% depending on the relative humidity of the skin (Kerslake, 1972). The concept of relative humidity of the skin (ϕ_s) has been developed to take account of the total heat of evaporation. Extra energy is absorbed in expanding the water vapour to $\phi_s P_s$. i.e. non-saturated water vapour pressure at the skin's surface. Thus the total heat of evaporation from the skin's surface (λ_s) increases as ϕ_s decreases at lower sweating rates. When ϕ_s decreases from 1.0 to 0.2, λ_s increases by about 10%. ϕ_s can be defined in terms of wettedness by the following equation.

$$\phi_s = w + (1 - w)P_a/P_s$$

where $w = E/E_{max}$

P_a = vapour pressure of the air

P_s = saturated vapour pressure at the skin's temperature

ϕ_s can not be calculated unless the proportion of evaporated sweat is measured. If ϕ_s is unknown the error in estimating λ_s can be as large as 10%. In most thermoregulation studies an error of this magnitude is unacceptable. To eliminate this conversion error it is suggested that weight loss be reported as a sweat rate rather than an evaporative heat loss.

Wenzel (1989) has looked at the effect of humidity when working at a metabolism of 236 Watts for four hours on a treadmill. It was found that the rectal temperature began to increase (non equilibrium) when the humidity of the environment was increased above a threshold level where the evaporative heat loss could no longer balance the metabolic heat production. eg. At T_a = 33°C the break away relative humidity for a non steady Trec was 80%. At T_a = 36°C the break away relative humidity for a non steady state was approximately 65%. At T_a = 40°C the break away relative humidity was approximately 50%. Since these experiments were at a light work rate it can be expected that humidity will become limiting at even lower air temperatures at moderate and heavy work rates. Wenzel (1989) found that the steady state limit in these light work conditions were T_{rec} = 37.8°C, T_s = 36°C and heart rate = 97 bts.minute^{-1}.

Kerslake (1972) found the equilibrium skin temperature to be 36°C at various relative humidities up to 80% when resting in 36°C air temperatures. When the relative humidity rose above 82% the skin temperature rose rapidly to increase the vapour pressure difference between the skin's surface and the air to maintain the required evaporation. Wells (1980) in a review on the effects of hot environments on physical performance stated that the shell temperature must be 1.2°C below the core temperature for thermo-equilibrium to be maintained. Thus a T_s equal to 36°C is the upper limit for light work. If the skin temperature rises above this level the shell becomes an insulating barrier and internal body temperatures will rise rapidly and reduce work capacity.

Gupta (1981) studied the effect of exercising at different metabolic intensities in hot humid conditions (RH=60%). He conducted three experiments with air temperatures at 27°C, 37°C and 40°C where the subjects exercised at three work rates (400, 500 and 600kgm.min^{-1}). The rectal temperature appeared to reach a plateau when the subjects were exercising at the three work levels in an air temperature of 27°C and the subjects could all continue exercising for longer than 90 minutes. In the two hot humid environments the subject's exercise bouts were terminated earlier than 90 minutes when heart rates reached 180 beats.min^{-1}. The greater the work rate the sooner the exercise bouts were terminated. At a work rate of 400kgm.min^{-1} the rectal temperature continuously increased up to approximately 39°C. After an initial rise during the first 20 minutes the skin temperatures plateaued. At the highest work rate of 600kgm.min^{-1} both the rectal and skin temperatures continued to rise until the test was terminated with heart rates of 180 beats.min^{-1} and a rectal temperature of 39°C. These exercise tests in hot humid conditions, with air temperatures at or above initial core temperatures, resulted in a nonequilibrium thermoregulatory strain on the subjects. The two higher work rates led to a more rapid storage of heat in the subjects and an earlier termination of the exercise tests.

Drinkwater (1979) who compared young girls and college women exercising at 30% VO_2maximum in 35°C and 65% relative humidity found that the girls had a lower heat tolerance time (84.4 minutes) compared to the adults (100minutes) and 60% of the girls could not complete the full 100 minute walk. The girls were removed when they reached 90% of heart rate maximum. They seemed to be limited by their cardiovascular ability rather than T_{rec} which was 38.2°C. Prolonged tasks in humid environments with air temperatures below 35°C seem to be equally well tolerated by both children and adults (Bar-or, 1980).

Increasing levels of humidity have minimal effects on skin temperatures (Berger and Grivel,1989) but have large effects on increasing heart rate. Kamon (1982) reports that for each 0.13KPa increase in water vapour pressure above 1.7KPa there is an increase in heart rate of 1 bt.min^{-1} at a constant work rate between 25% and 50% VO_2max. T_a = 25°C and 54% relative humidity (P_a = 1.7KPa) are the baseline environmental conditions below which heart rate is minimally affected when individuals perform light to moderate work. Increasing the relative humidity to 70% (P_a =2.22KPa) at 25°C increases the heart rate by 9 beats.min^{-1}.

At 30°C there is an increase in heart rate of 5 beats.min^{-1} due to the increased air temperature and an additional 5 beats at a relative humidity of 55% (P_a = 2.35KPa) and an additional 10 beats at a relative humidity of 70% (P_a = 3.00KPa). At the higher temperatures there is more scope for increasing heart rates by raising water vapour pressure due to the warmer air's greater capacity to absorb water vapour.

At temperatures below 36°C it is difficult to predict the effect of humidity on children. Theoretically they should be superior to adults because their smaller size indicates that they will lose heat convectively faster than adults and also sweat less if there is an equal metabolic heat load. This enables them to thermoregulate more efficiently (i.e. less sweat) but does not predict the heart rate cost of moving metabolic heat from the core to the skin's surface.

AIR VELOCITY

The measurement of heat gain/loss depends on a realistic measurement of average air velocity. Air velocity dramatically affects the heat exchange coefficients h_c and h_e. The calculation of E_{max} in Table 14 used the equation $E_{max} = h_e(P_s - P_a)$. Table 14 demonstrates that increasing V from 1 to 4 m.sec^{-1} doubles h_e. This has been calculated for a unidirectional wind velocity moving past a fully wet stationary subject. In the sporting situation the wind velocity relative to the movement of the human body is generally more important than the environmental wind velocity. If a runner is moving at 15km.hr^{-1} (4 m.sec^{-1}) in still air his/her relative air speed is 4 m.sec^{-1}. This is complicated by several factors:

1. Head and tail winds increase and reduce the relative wind velocity.
2. Local air velocity is different on the legs and arms which are alternatively moving faster and slower than the rest of the body.
3. The local evaporative coefficient (h_e) can be quite different on the back and front of the subject. The front is dry and the back is often wet.
4. In team games the effect of the environmental air velocity is omnidirectional as the subject moves in different directions.
5. Wind velocities fluctuate over time.

While there is a lot of error in estimating an average air velocity for the human body in different working conditions, it is better to make an estimate than none at all since it has such a dramatic effect on the convective and evaporative heat losses.

In the ten Australian cities measured (Table 15) wind speed generally lies between 1 - 30km.hr^{-1} with higher wind speeds in the afternoon; at least in January. There is considerable variability between cities and at different times of the day. The effect of these different wind speeds on temperature regulation needs to be taken into account. The average wind speed without direction in Australia's state capital cities is 15km.hr^{-1}.

Table 15. Percentage of wind speeds in each speed range without direction for January

Speed ($km.hr^{-1}$)	0	1-10	11-30	>30	0	1-10	11-30	>30
	January 9am				January 3pm			
City								
Adelaide	8	42	46	4	1	16	75	8
Perth	5	27	63	5	0	10	80	10
Melbourne	13	32	53	2	1	25	70	4
Broken Hill	6	27	58	9	14	35	48	3
Alice Springs	18	33	45	4	7	26	62	5
Darwin	20	38	38	4	3	23	70	4
Townsville	19	31	50	0	3	16	77	4
Brisbane	16	45	38	1	2	24	72	2
Coffs Harbour	0	22	70	8	3	9	58	30
Sydney	8	36	52	4	0	7	85	8
Ten Cities $\overline{X}$	11.3	33.3	51.3	4.1	3.6	19.1	69.7	6.8

Australian Climatic Atlas.

Shaffrath and Adams (1984) have looked at the effects of airflow on cardiovascular drift and skin blood flow. They used eight fit adult males with an average VO_2maximum = 58.8 $ml.kg^{-1}.min^{-1}$ and an average fat level = 8.7%. The exercise tests were performed at 43% and 62% of VO_2maximum in T_a = 24°C.

Table 16 indicates that minimal air flow particularly stresses subjects who are working at high work rates and producing a lot of metabolic heat. In fact T_{rec} has not reached an equilibrium core temperature towards the end of 70 minutes of cycling. Also these conditions show the greatest sweat rate of 1.2 $l.hour^{-1}$ and the greatest cardiovascular drift of 22 $beats.min^{-1}$. Shaffrath and Adams (1984) concluded that cardiovascular drift occurs only in conditions of high combined metabolic and thermal circulatory demands and this is consistent with a drained splanchnic reserve and a progressive redistribution of blood from central to cutaneous circulations. Evidence for this drift is an increased forearm blood flow (+14ml) and a decreased mean arterial pressure (-11mmHg) and a decreased stroke volume (-16ml).

Table 16. Cardiovascular and thermoregulatory variables measured at different wind speeds and work rates.

Wind Speed ($m.sec^{-1}$)	0.2	0.2	4.3	4.3
VO_2max (%)	43	62	43	62
Variables				
Change HR ($b.min.^{-1}$)	0	22 (range 8 - 35)	0	8
Change FBF ($ml.100ml^{-1}$)	-1	+14	+3	+4
Change MAP (mmHg)	-7	-11	0	+2
Change SV (ml)	0	-16	+3	-3
T_{rec} (°C)	37.9	38.5*	37.7	38.2
T_s (°C)	31.2	31.2	29.0	28.8
Sweat Rate ($l.hr^{-1}$)	0.38	1.20	0.60	0.90

Compiled from Shaffrath and Adams (1984)

HR is heart rate FBF is forearm blood flow MAP is mean arterial pressure
SV is stroke volume * non equilibrium

Brown and Banister (1985) supported the previous findings by comparing standard laboratory cycling (no fans or lamps) with simulated road cycling and found higher heart rates and greater sweat rates (+7 $bts.min^{-1}$, +0.5kg.90 min^{-1}) in the standard laboratory conditions. In addition they compared the laboratory simulated conditions with actual road cycling. Although fan speeds were 10.7$m.sec^{-1}$ compared to a 8.3$m.sec^{-1}$ effective air speed on the bike (due to a riding speed of 8.3$m.sec^{-1}$) the road cycling condition maintained a lower T_{rec} (T_{rec} = 37.2°C versus T_{rec} = 38.0°C), a similar weight loss and a higher heart rate (161 versus 144 $b.min^{-1}$) than the laboratory conditions. A limitation of this experiment was the outdoor air temperature (T_a= 14-15°C) versus the higher laboratory air temperature. Further study needs to be done on the effect of wind on the cardiovascular and thermoregulatory responses in outdoor environments.

Hirata (1987) studied the effects of facial fanning on eight subjects performing repetitive hand grip exercises at 20% of maximal effort (30 $contractions.min^{-1}$) in T_a = 35°C and relative humidity = 75%. Hyperthermia was induced by 27-29 minutes of leg immersion in a 42°C water bath. This raised the core temperature by 0.5°C (both oesophageal and tympanic temperatures). Facial fanning at 5.5$m.sec^{-1}$ caused a marked decrease in forehead skin temperature (1.5 -2.0°C) and a slight decrease in T_{ty} (0.2°C) and a decreased heart rate (4.2%) when compared to a non fanning situation. Performance improved from 310 to 431 contractions with facial fanning. It is suggested that there is a local counter current heat exchange between the cooler blood in the jugular vein (drains from the face) and the warmer blood in the carotid artery. The lower T_{ty} might reflect local brain cooling which results from facial skin cooling.

As yet the relative effects of wind on the thermoregulation of children and adults has not been studied but it is important to simulate the natural environmental conditions as closely as possible to realistically compare the thermoregulatory responses of adults and children

Berger and Grivel (1989) looked at predicting mean skin temperatures for a stationary subject in warm humid climates with air temperatures between 24°C and 34°C. They found that T_s decreased as air velocity increased. For each 1 m.sec^{-1} increase in wind speed T_s decreased by 0.33°C.

The effects of a breeze was well demonstrated on the heat exchange variables measured in a climate chamber and outdoors in an open cut mine in tropical Australia (Brotherhood,1987). Metabolic heat production was 350 Watts. Table 17 demonstrates that the increased air speed in the chamber increased the convective heat loss quite considerably. E_{req} was only more than E_{max} in the chamber when there was no breeze which means that heat was being continuously stored in the subject. The reduced humidity in the open cut mine combined with a moderate wind velocity of 1.0 m.sec^{-1} allowed E_{max} to exceed E_{req}. Equilibrium body temperatures were then established.

Table 17. The comparison of environmental and heat exchange variables in a climate chamber and an open cut mine in tropical Australia.

Environmental conditions Variables	Climate Chamber no breeze	Climate Chamber breeze	Outdoors Sunlight+breeze
T_w °C	22.7	22.7	21.1
T_a °C	28.0	28.0	28.3
T_g °C	29.3	28.8	41.1
V m.sec^{-1}	0.15	1.53	1.0
P_a kPa	2.4	2.4	2.0
RH %	63	63	53
heat exchange variables			
R W	-30	-25	227
C W	-21	-86	-63
$R + C$ W	-51	-111	164
E_{req} W	297	238	513
E_{max} W	152	611	533

Brotherhood (1987)

In summary, convection and evaporation are both very important avenues of heat loss when individuals exercise at high metabolic heat loads with air temperatures below 36°C. Both avenues of heat loss are greatly affected by wind velocity.

BODY SIZE AND SHAPE

Thermoregulation is directly affected by body size; as children are smaller they have a larger surface area per mass ratio and gain heat at a faster rate by convection and radiation. Convective heat gain generally occurs once the air temperature is above 36°C. Radiant heat gain depends on the angle of the sun's rays and the area of skin exposed to the sun's rays. The following discussion analyses the theoretical and practical differences between children and adults due to size.

Asmussen (1974) assumed that adults are approximately 50% taller than eight year old children. He also assumed constant body proportions as the child grows into an adult. Theoretically the surface area is proportional to height squared; the surface area of the adult is 2.25 times larger that the child's. Similarly, volume is proportional to height cubed and therefore the adult's volume is 3.375 times larger than the child's (Table 18). Consequently, the surface area per volume ratio is theoretically calculated as 50% greater in children compared to adults.

Table 18. Size comparison of children and adults.

Dimensions	Children	Adults
Height	1	1.5
Surface area	1	$(1.5)^2 = 2.225$
Volume	1	$(1.5)^3 = 3.375$
Surface area/volume	1	$\frac{2.225}{3.375} = 0.67$

Asmussen, 1974

In boys, the assumption of constant linear proportions during growth does not hold, as weight increases proportionally to height to the power 2.7 ($Ht^{2.7}$) rather than height cubed as expected (Asmussen, 1974). Also there are widely varying builds among adults and children and the variation in thermoregulation because of these different builds should be taken into account. The above limitations make it necessary to use actual measurements of surface area and mass. The Dubois surface area formula of $SA = .00718 \times Wt^{0.425} \times Ht^{0.725}$ is sufficiently accurate for both children and adults (Martin, 1984). Using Tanner's (1978) United States cross sectional data of growth in height and weight, surface area per mass can be calculated for a wide variety of sizes of ten year old boys and eighteen year old men (Table 19).

Table 19. Comparison of physical dimensions of children and adults.

Status	10 year old boys				18 year old men			
Variables	Height	Mass	Surface Area	SA/Mass	Height	Mass	Surface Area	SA/Mass
Centile	cm	kg	m^2	$cm^2.kg^{-1}$	cm	kg	m^2	$cm^2.kg^{-1}$
10	130	25	0.96	384	168	58	1.66	286
50	138	32	1.11	347	176	69	1.84	267
90	146	41	1.29	315	185	89	2.13	239

The average ten year old ($347cm^2.kg^{-1}$) has 30% more surface area in relation to mass than the average adult ($267cm^2.kg^{-1}$). The variation around this mean for the 10th and 90th centiles in growth is approximately ±10% for each group. The greater surface area per mass ratio is an advantage at air temperatures below 36°C as heat is lost by convection at a faster rate due to the ambient temperature being less than the skin temperature. When the ambient temperature rises above 36°C the children will still lose heat by evaporation of sweat but will gain heat by convection more quickly than adults. The skin temperature remains above the environmental temperature up to 36°C and below the environmental temperature in hotter environments so that a positive core to skin temperature gradient can be maintained and continue to remove metabolic heat (Haymes, 1984). This apparent division at 36°C might be higher during heavy exercise when the core temperature rises from 37°C up to 39°C but this more dynamic situation needs further research.

Since metabolic heat production is mainly proportional to mass, ten year old children could produce the same metabolic heat/kg as young adults when both are exercising at the same relative intensity (assuming equal cardiovascular fitness). In fact, the children are likely to produce more metabolic heat/kg because they are less efficient than adults when exercising at the same relative intensity. This disadvantage of extra heat production could be reversed to some extent by the children's greater rate of convective heat loss due to their surface area per mass advantage in temperatures below 36°C. It is important to carefully assess both heat loss and heat production for children and adults exercising in hot wet and hot dry environments so that an objective comparison between the thermoregulation of children and adults can be established.

The shape of adults is important for temperature regulation with the more linear individuals losing convective heat at a faster rate in air temperatures less than 36°C because of their greater surface area per mass ratio. The ponderal index can be used to assess linearity in both children and adults. The ponderal index calculated from Tanner's 1978 data showed that the small 10 year old children (44.4) were more linear than the large adults (40.1) while average 10 year old children and average adults had almost identical values of 43.4 and 42.9 respectively. Schickele (1974) states that "men 2-7 kg above the normal weight for their height were four times more susceptible to heat stress than men of average weight. Also men of average weight were four times more susceptible than those who were more than 7 kg below average for their height and age". This statement referred to adults exercising at high metabolic heat loads in hot wet climatic conditions. In these conditions it is harder for the less linear individuals to dissipate metabolic heat by radiation, convection and evaporation because they have a smaller surface area/mass ratio. More recently Docherty (1986) looked at the body shape of children and adults walking on the treadmill at 6 km.hr^{-1} and 7 km.hr^{-1} respectively for 60 minutes in hot (T_a = 30°C) humid (80% relative humidity) conditions. He found that adults with a mesomorphy rating greater than 7 and a surface area per mass ratio less than 240 cm^2·kg^{-1} were at risk of heat exhaustion when exercising under these conditions. Eleven and twelve year old boys thermoregulated efficiently and were not at risk in these conditions as they had a much larger SA/Mass ratio ($\bar{X}$ =320 cm^2.kg^{-1}) than the men ($\bar{X}$ = 252 cm^2·kg^{-1}) and did not have the diverse range of mesomorphy of the adults. Only the obese children were at risk under these conditions with low but significant correlations between increases in rectal temperature and endomorphy ($r = 0.41$) and between increases in rectal temperature and aerobic fitness ($r = -0.40$).

Epstein (1983) compared two groups who stepped onto a 30cm bench at 12 steps per minute for 3 hours in 40°C and 40% relative humidity (Table 20). One group was classed as heat intolerant due to exhaustion and a T_{rec} > 39°C. The other group completed the task with a T_{rec} = 37.8°C. Epstein (1983) found that both the surface area per mass ratio and work efficiency were highly correlated with heat tolerance. Table 20 demonstrates that the heat intolerant group had a 10% smaller SA/Mass ratio compared to the other two groups and had a 15% lower efficiency than the control group. The effect of these two factors is a heart rate 35 beats per minute higher and a T_{rec} 1.0°C higher that the other two groups. Fitness as measured by VO_2 maximum was not a factor when subgroups from the original groups with equal VO_2 maximum values were compared. A more complete comparison could have been made if percentage fat differences between the groups had been taken into account.

Table 20. Comparison of thermoregulatory variables of the heat intolerant group with the heat tolerant and control groups.

Group Variables	Heat intolerant	Heat tolerant	Control
Mass (kg)	77.8	65.2	67.5
Height (cm)	173	173	177
SA/Mass(cm^2. kg^{-1})	247	271	272
VO_2max (ml.kg^{-1}.min^{-1})	40.0	52.2	49.0
Efficiency (%)	10.2	10.4	11.8
HR - 2 hrs (b.min^{-1})	159	124	118
T_{rec} - 2 hrs (°C)	38.9	37.9	37.9

Epstein (1983)

METABOLIC EFFICIENCY

Children performing at the same work rate as adults when running and cycling do not have an equal metabolic heat production per kg. This is because children are less efficient at running (Bar-or, 1980), and cycling on an ergometer (Lawson, 1983). Children are up to 30% less efficient than young adults when both are performing at the same speed.

Haymes (1975) found that the oxygen consumption per kg body mass for boys was reduced to approximately the same value as for middle aged men when the children walked on a level treadmill compared to the adults walking at the same speed on a 5% grade. Bar-or (1980) has also found significant differences between the metabolic efficiency of children and adults walking on the treadmill at 4.8 $km.hr^{-1}$. He demonstrated that 9-11 year old girls required a VO_2 of 21.5 $ml.kg^{-1}.min^{-1}$ whilst 18-22 year old women required a VO_2 of 18.0 $ml.kg^{-1}.min^{-1}$. Bar-or (1983) also reported an 8 $ml.kg^{-1}.min^{-1}$ (20%) difference when 5 year old children and 17 year old adolescents ran at 10 $km.hr^{-1}$. More recently, Rowlands (1987) has observed large differences between prepubertal boys and non-athletic adult males. Running at 9.6 $km.hr^{-1}$ the adults and boys demonstrated an oxygen uptake of 40 and 49.5 $ml.kg^{-1}.min^{-1}$ respectively. This difference was not due solely to differences in resting metabolism which was 2.4 $ml.kg^{-1}.min^{-1}$ higher in the young children (Table 21), but was also due to an immature respiratory system and poor running technique. This increased metabolic heat production per kilogram of body weight is a distinct disadvantage for children exercising at the same work rate as adults in hot conditions.

Table 21. Basal metabolic rate of 10 year old boys and young adult men.

Status	Age yrs	Height cm	Weight kg	Basal Metabolic Rate $ml.kg^{-1}.min^{-1}$
Boys	10	137	30.4	5.9
Men	33	180	77.4	3.5

From Thorstensson (1986)

When considering temperature regulation studies in children and adults, it is important to measure the gross efficiency of the individual as it is the total oxygen uptake minus work rate which contributes to the heat production. On a bicycle ergometer gross efficiency is essentially the same as metabolic efficiency.

$$\text{i.e. Gross Efficiency} = \frac{\text{Work}}{\text{Energy expenditure}} \times 100$$

$$\text{Mechanical Efficiency} = \frac{\text{Work}}{(\text{Metabolism - Resting Metabolism})} \times 100$$

with its allowance for resting metabolic rate is inappropriate for heat studies as the resting metabolic rate also contributes to the heat production of the individual.

In cycling studies, mechanical efficiency is usually measured instead of gross efficiency. Bar-or (1983) claims that mechanical efficiency is similar in children and adults ranging between 18 and 30%. More recently, Klausen (1985) has found that small children working at a heart rate of 130 $beats.min^{-1}$ had a mechanical efficiency of 13%. This is almost 10% lower than the mechanical efficiency found in adults. Mechanical and metabolic efficiencies are hard to compare between children and adults because other factors will effect the efficiencies of children and adults to different extents. i.e.

i) the length of the pedal crank,
ii) the frame size of the bicycle,
iii) the amount of energy lost in the chain drive and flywheel, and
iv) the error involved in setting work rates on different Monark ergometers.

FAT

Haymes (1975) looked at the heat tolerance of lean and obese boys exercising in different environments. The boys walked on a treadmill at 4.8 $km.hr^{-1}$ and up a 5% grade. The different environmental temperatures for the treadmill walk were 26°C, 36°C, 42°C and 48°C with low relative humidities (22 -25%). The obese children of this study walked at a 7% higher percentage of VO_2maximum than the lean children (Table 22) and therefore were exercising at higher heart rates and core temperatures. The lean children were exercising at a 10% higher relative VO_2 ($ml.kg^{-1}.min^{-1}$) than the obese group which indicates that they had a higher relative heat production and necessarily needed to sweat more to lose heat. Also, the lean group had a 21% greater surface area per mass ratio than the obese group which meant that they absorbed convective heat faster than the obese group at air temperatures above 36°C.

Table 22. Physical and physiological characteristics of lean and obese prepubertal boys and their submaximal oxygen consumption.

Subjects Variables	Obese	Lean
Age (yrs)	10	10
Weight (kg)	51.4	33.5
Surface Area (m^2)	1.45	1.15
SA/Mass ($cm^2.kg^{-1}$)	284	345
Fat (%)	31	15
VO_2max ($ml.kg^{-1}.min^{-1}$)	40	51
VO_2 ($ml.kg^{-1}.min^{-1}$)	20.2	22.1
%VO_2max	50	43

Adapted from Haymes (1975).

In 48°C air temperatures the core temperatures of both the lean and obese children did not reach thermal equilibrium. This was probably due to both groups reaching maximal sweat rates and not being able to supply enough evaporative cooling power (Table 23). In the 42°C heat the lean children reached thermal equilibrium while the obese children demonstrated continually increasing core temperatures. The disadvantage of the lean group's surface area per mass ratio exercising in very hot conditions was negated by their 8% higher specific heat and greater aerobic fitness. Specific heat was 0.78 and 0.72 $Kcal.kg^{-1}.°C^{-1}$ for the lean and obese groups respectively. The lean children also reached this equilibrium because they were able to evaporate sweat at close to the maximal rate while maintaining a low final heart rate of 135 $b.min^{-1}$.

Table 23. Relative evaporative heat loss rates for lean and obese children at different air temperatures.

Group	26°C	36°C	42°C	48°C
Lean children	4.47*	7.28	10.47	11.27
Obese children	4.02	5.36	5.93	8.22
Differences	10%	35%	76%	37%

Adapted from Haymes (1975) *Units $W.kg^{-1}$

The obese children did not reach thermal equilibrium because their evaporative sweat rate was below the required rate to lose sufficient heat but it was also below their maximal sweat rate (Table 23). The obese group's high final heart rates (162$b.min^{-1}$) indicate that they were cardiovascularly stressed and perhaps this induced a vasoconstriction which reduced the skin's blood flow and led to a smaller than optimal evaporative sweat rate. Both the lean and obese children were in thermal equilibrium in the 36°C heat. It appears from this study that the leaner fitter children can tolerate walking in hotter environmental conditions (up to 42°C), while the obese are at risk of excessive heat stress which is likely to lead to heat exhaustion. The main limitation of this study was that the obese children were walking at a higher relative percentage of VO_2maximum (+7%) and consequently were expected to have higher core temperatures and heart rates. To effectively evaluate the thermoregulatory differences between fat and lean prepubertal boys both groups should be exercising at the same percentage of VO_2maximum. The main reason for the lesser heat tolerance of the obese boys exercising at the same work rate as the lean boys was their lower aerobic fitness which created a higher relative effort and therefore a greater physiological and thermoregulatory strain.

Theoretically fat people will heat up faster than lean individuals, because the specific heat of fat is 0.4 $Kcal.gm^{-1}.°C^{-1}$ compared to water with a specific heat of 0.98 $Kcal.gm^{-1}.°C^{-1}$. The specific heat of fat free body mass is 0.8$Kcal.gm^{-1}.°C^{-1}$. Children can have a wide range of body fatness. At this stage the relative fatness of children and adults estimated by body density has not been realistically compared because the Siri equation which is generally used for adults cannot be used for children (Lohman,1987). Lohman (1989) has established that children have a different fat free body density to adults which was assumed to remain constant at close to 1.10 g.cc^{-1}. As children mature their percentage body water decreases (Table 24) from 79% to 74% for males and from 79% to 75% for females. Also the bone mineral percentage increases from around 4% to over 6% of body weight for both sexes. Both these factors appreciably affect the average lean body density which increases by approximately 0.03 from a young child to maturity. If the Siri equation is used for the conversion this change in body density leads to a change in the calculation of percentage fat from 6 to 19%. To achieve accurate percentage fat measurements; percentage body water, percentage bone mineral and body density need to be measured. If an average percentage water and an average percentage bone mineral for a given age is placed in Lohman's revised formulas up to 5% errors in percentage fat can occur. It is therefore suggested that Lohman's 1989 formula with its direct measurement of % body water and bone mineral % should become the gold standard for percent fat measurements.

i.e. $\%Fat = \left(\frac{2.749}{D_b} - 7.14\,W + 1.146\,B - 2.0503\right) \times \frac{100}{1}$

W = %body water. B = %bone mineral

Table 24. Fat free body composition and density in children.

Sex	Male			Female		
Variables	Water %	Bone Mineral %	Fat-free density g.cc^{-1}	Water %	Bone mineral %	Fat-free density g.cc^{-1}
Age (yrs)						
1	79.0	3.7	1.068	78.8	3.7	1.069
1-2	78.6	4.0	1.071	78.5	3.9	1.071
3-4	77.8	4.3	1.075	78.3	4.2	1.073
5-6	77.0	4.8	1.079	78.0	4.6	1.075
7-8	76.8	5.1	1.081	77.6	4.9	1.079
9-10	76.2	5.4	1.084	77.0	5.2	1.082
11-12	75.4	5.7	1.087	76.6	5.5	1.086
13-14	74.7	6.2	1.092	75.5	5.9	1.092
15-16	74.2	6.5	1.096	75.0	6.1	1.094

Lohman (1989)

In conclusion, unless very accurate methods are used it is inappropriate to compare percentage fat of children and adults because of the large conversion errors occuring in the different population specific %fat equations. If sophisticated equipment is not available it is suggested that the four skinfolds; tricep, calf, thigh and abdomen be used to estimate body fatness. Slaughter (1984) has found these sites to be the best predictors of body density in children. To eliminate the different %fat conversion errors from skinfolds to %fat between adults and children it is suggested that for comparison purposes the sum of the above four skinfolds gives a reasonable estimate of subcutaneous fat.

High levels of subcutaneous fat does not act as an insulation layer for heat loss in hot conditions. Body heat is effectively transmitted to the skin in hot climates due to the elimination of vasoconstriction of the arterioles supplying blood to the skin and a further active vasodilation of these arterioles as the body heats up due to exercise (Rowell, 1986). When the skin is maximally vasodilated blood flows of up to 7-8 $L.min^{-1}$ can occur. This effectively moves the body's heat to the skin's surface for radiative, convective and evaporative dissipation. Acral body structures such as the fingers, toes, nose and ears do not possess an active vasodilation system but their importance in thermoregulatory responses to heat stress is small (Rowell,1986).

Docherty (1986) also found that obese prepubertal children are prone to exercise heat strain when walking on a treadmill at 6 $km.hr^{-1}$ in 30°C heat and 80% humidity. These children were generating more metabolic heat than lean children and also working at a greater percentage of their aerobic capacity. This result is similar to the one found by Haymes (1975) but does not realistically assess the effect of the smaller specific heat of the fat child. To do this both the obese and lean children would need to be working at the same percentage of VO_2maximum.

AEROBIC FITNESS

It appears that average prepubertal children have a similar aerobic power to active young adults. Prepubertal boys who have been directly measured for VO_2maximum often score between 50 - 55 $ml.kg^{-1}.min^{-1}$ which is comparable to young men who remain physically active (Table 25).

Table 25. Reference values for aerobic power of healthy 6-18 year old Dutch children

Sex	Age yrs	n	VO_2max $ml.kg^{-1}.min^{-1}$	Heart Rate max $b.min^{-1}$
Boys	6	7	47.0	203
	8	7	53.0	207
	10	8	52.7	205
	12	6	53.0	206
	14	11	51.1	203
	16	10	55.1	202
	18	9	51.7	198
Girls	6	7	47.2	205
	8	11	43.0	203
	10	5	56.8	205
	12	10	46.5	208
	14	11	44.6	200
	16	9	42.6	196
	18	10	41.6	200

Data from Saris (1985).

The measurement of aerobic power of average prepubertal girls varies between 43-48 ml.kg^{-1}.min^{-1} up until puberty after which it gradually declines as the percentage of body fat increases. Prepubertal girls are considered to have a 10% greater aerobic fitness than young women who remain physically active (Bar-or, 1983). Maximum heart rates (Saris, 1985) average just above 200 bts.min^{-1} for both girls and boys.

Gauthier (1988) on a very large sample of Canadian school children has produced a percentile table of predicted VO_2maximum from an endurance run for performance of male and female children between six and seventeen years of age (Table 26). These norms have been validated by direct measurements of VO_2maximum on 573 subjects using a bicycle ergometer. The predicted VO_2maximum values had a standard error estimate of about 5 ml.kg.$^{-1}$min^{-1} in each of the three age categories. The multiple correlation between direct VO_2maximum, body mass and running time was 0.76 for the six to nine year olds, 0.80 for the 10-12 year olds and 0.82 for the 13-17 year olds. The running distances were 800m, 1600m and 2400m for the three age groups, respectively.

Table 26. Percentiles by age group and sex for VO_2maximum predicted from the endurance run time and weight of Canadian youths.

Age groups (yrs)	6-9		10-12		13-17	
Sex	males	females	males	females	males	females
Centiles						
99	63.4*	57.4	62.1	57.5	66.5	57.7
95	59.6	54.4	60.0	55.3	62.9	54.3
90	57.2	52.3	58.6	53.6	60.8	52.1
85	55.6	50.8	57.7	52.6	59.6	50.6
80	54.5	49.7	56.7	51.6	58.5	49.4
75	53.4	48.6	55.9	50.7	57.7	48.4
70	52.3	47.7	55.3	49.9	56.9	47.7
65	51.3	46.8	54.6	49.0	56.1	46.8
60	50.5	45.7	53.9	48.3	55.4	46.1
55	49.5	44.9	53.1	47.5	54.6	45.3
50	48.3	43.9	52.3	46.7	53.8	44.6
45	47.4	43.1	51.2	46.0	52.7	43.9
40	46.2	42.3	50.4	45.2	51.9	42.5
35	45.1	41.2	49.4	44.4	50.9	41.8
30	44.0	40.3	48.1	43.6	48.9	41.0
25	42.7	39.0	46.9	42.7	48.9	39.9
20	41.5	37.7	45.6	41.8	47.7	39.9
15	40.0	36.3	44.4	40.5	45.6	38.8
10	37.7	34.4	42.9	38.5	43.5	37.7
05	34.0	31.8	39.3	36.5	39.7	35.5
01	21.6	24.0	27.2	23.1	26.8	30.1

Gauthier (1988) *units ml.kg^{-1}.min^{-1}

The percentile tables (Gauthier, 1988) are in approximate agreement with the Saris (1985) data previously displayed with average males scoring predicted VO_2maximum values of 48, 52 and 54 $ml.kg^{-1}.min^{-1}$ respectively for the three age categories. The average females scored predicted VO_2maximum values of 44, 46 and 44 $ml.kg^{-1}.min^{-1}$ which is also similar to the Saris data. The percentile tables also demonstrate that children have a wide spread of predicted VO_2maximum values which indicates that children have a similar spread of aerobic fitness levels to adults. It cannot be said that adults have similar average aerobic fitness scores to children because this depends greatly on the normal activity levels which the adults maintain. It is suggested that if both children and adults maintain optimal physical activity levels that they will elicit similar average aerobic fitness values as measured by VO_2maximum. A Japanese study on a group of children between the ages of six and eighteen years old has also found similar average VO_2maximum values to Saris. Table 27 demonstrates that while aerobic power remains relatively constant in boys there is a 43% improvement in endurance performance between the ages of six and eighteen. Girls improve 37% up to the age of fourteen and then decrease in parallel with a decrease in aerobic power. It is hypothesized that this lower endurance capacity of children measured by a five minute run is due to their lower metabolic efficiency and lower levels of muscle strength (Rowland, 1989). These physical differences between children and adults imply that children have a lower work capacity and are likely to fatigue more quickly than adults when exercising at the same work rate.

Table 27. Aerobic power and 5 minute endurance performance of boys and girls.

	n		Body mass (kg)		VO_2max ($ml.kg^{-1}.min^{-1}$)		5 min run (m)	
Age (yrs)	M	F	M	F	M	F	M	F
6	35	24	21.1	19.6	49.3	45.6	934	824
8	35	23	26.2	25.2	52.0	47.7	1026	915
10	23	13	29.0	31.5	53.4	49.5	1085	983
12	34	26	35.9	37.6	52.5	47.7	1199	1094
14	21	19	46.6	46.5	55.2	44.0	1302	1123
16	23	17	54.6	49.2	54.9	43.6	1327	1064
18	7	9	57.3	51.7	52.4	40.1	1340	1024

Yoshizawa (1986)

In the literature, heat studies comparing children and adults have often used the same absolute work rate. Aerobic fitness is only an important factor in heat tolerance when the individuals being compared exercise at the same absolute work rate. The more physically fit person will possess greater heat tolerance than the one who is less physically fit.

Hori and Ihzuka (1979) tested eight young male subjects at a constant work rate of 450 $kgm.min^{-1}$ in 30°C and 79% relative humidity and found that there were high correlations between heat production and rise in T_{rec} (r = 0.89) and percentage change in mass due to sweat loss (r = 0.81). The correlations of work rate as a percentage of maximum work rate were much lower. Hori and Ihzuka (1974) have demonstrated that it is the percentage of maximum heat production that gives the relative metabolic heat stress rather than the percentage of maximum work rate. Davies (1987) exercised children and adults at 69% of VO_2maximum and found that the T_{rec} for both groups rose to 38.8°C. The children and adults also had similar VO_2maximum values of 65 and 68 ml.kg.$^{-1}$min^{-1} respectively. Gullestadt (1975) tested eleven year old boys at various relative intensities and found that boys exercising at 50% of VO_2maximum obtained a T_{rec} of 37.9°C. Saltin and Hermansen (1971) found that twenty to thirty year old adults exercising at 50% VO_2maximum attained a T_{rec} = 38.1°C, which while higher is close to that found for children.

Gullestad (1975) states that the rise in rectal temperature is less in children because they start from a higher resting level (+ 0.6°C) than adults. Adams (1989) supports this position with her study of men and women of different body masses and measurement of resting oral temperatures. She found that the mean oral temperature measured over 16 hours was inversely proportional to body mass (r = -0.44). This has also been found across and between other homeothermic species and obeys the laws of thermodynamics. Body temperature is inversely related to body mass because metabolic rate and rate of heat loss are also both inversely related to body mass. This inverse relationship between body mass and core temperature appears to also hold for children although there could be extra heat storage due to the metabolism of growth.

CHAPTER 3

METHODS

This study was conducted in two parts. The first part involved a comparison of the physiological and thermoregulatory responses between adults and children exercising in theoretically equivalent hot dry and hot wet climatic conditions without radiant heat. The second part involved comparisons of physiological and thermoregulatory responses between adults and children exercising in hot wet climatic conditions with varying levels of radiant heat and varying levels of metabolism.

PART A: CHILDREN AND ADULTS EXERCISING IN HOT WET AND HOT DRY CLIMATIC CONDITIONS WITHOUT RADIANT HEAT

RESEARCH DESIGN

The aim of part A of the study was to compare the physiological and thermoregulatory responses of children and adults exercising in commonly occurring hot conditions without radiant heat. The research design utilised a three way analysis of variance with a discrete variable for status (child, adult) and repeated measures on climate (3 levels) and time (6 levels). The independent variables involved in this design were:

Status - children and adults.

Climate- the subjects repeated the exercise test at air temperatures equal to 22°C, 31°C and 35°C.

Time - measurements were repeated on the subjects at 5 minute intervals during the 30 minute exercise test.

This analysis was generally performed separately for the male and female subjects involved in this study.

While there was an attempt to equalize the heat stress applied by the hot wet and hot dry climate via the effective temperature index, no attempt was made to compare the physiological effects of these two different climatic types. Instead, the emphasis was placed on the differences between adults and children in each of the hot climates and also on how the physiological and thermoregulatory responses differed to the neutral climate.

SUBJECTS

Twenty undergraduate physical education students (ten males and ten females) from Victoria University of Technology volunteered for the adult group of the study. Informed consent and the approval of the Victoria University of Technology Ethics Committee were obtained prior to the commencement of the study. Later, three adult subjects withdrew from the study. One male withdrew because of a hamstring injury, one female did not want to complete the strenuous thirty minute climate chamber tests, whilst another female had an aversion to the temperature sensing ear canal probe. One female was eliminated from the analysis of the data due to her working at reduced workrates in the two hotter climate chamber tests in comparison to the neutral climate chamber test. The 16 subjects who completed the study were at various levels of aerobic fitness. Three of the subjects (two males and one female) were in serious training for triathlon and long distance running events, while the main physical activities of the remainder were undertaken within the human movement courses conducted by the Department of Physical Education and Recreation.

Twenty-nine children from grades five and six at Ascot Vale Primary School volunteered for the study. Prior permission for the conduct of the study was given by the Victorian Education Department and the Victoria University of Technology Ethics Committee and a consent form signed by the parents of the subjects. All the children were active in school sports but none trained seriously for elite level sport. A total of nine children withdrew from the study. Six girls felt that it would be too strenuous exercising in the heat for thirty minutes and two boys had an aversion to the ear probe, whilst another boy left the district. Ten boys and ten girls completed the study.

The data of five children (3 girls, 2 boys) were withdrawn from the analysis due to their working at reduced workrates in the two hotter climate chamber conditions in comparison to their workrate in the neutral climate chamber condition.

Since all of the subjects were from Melbourne and the study was conducted in the cooler months of the year, it was assumed that none of the subjects were acclimatized to exercise in the hot wet and hot dry conditions established in the climate chamber.

RATIONALE FOR THE CHOICE OF TESTS

Anthropometric tests. Measurements were taken of variables which are likely to affect temperature regulation. These included the surface area/volume ratio as estimated by the surface area and mass of the person; the ponderal index because of its estimate of body shape and subcutaneous fat as measured by skinfolds. The estimation of percent fat by underwater weighing was considered to be inappropriate for comparisons between children and adults. The Siri equation used to convert body density to percent fat in adults over estimates percentage body fat in children (Lohman, 1989).

Cardiovascular fitness test. Cardiovascular fitness was measured by an incremental volitional termination VO_2maximum test on a cycle ergometer as it is known to be strongly related to an individual's response to a temperature stress test (Hori and Ihzuka, 1979). It was also important to measure VO_2maximum as the thirty minute climate chamber tests were to be conducted on a cycle ergometer at a workload which elicited 50% of VO_2 maximum.

Thermoregulatory tests. Three thirty minute exercise tests were conducted on a bicycle ergometer under the environmental conditions shown in Table 28. The air temperature, humidity and air velocity conditions were chosen to simulate normally occurring hot and neutral conditions in Australia. The air velocity of 4.0 $m.sec^{-1}$ is the average wind speed recorded in Australia's state capital cities (Bureau of Meteorology, 1979). The exercise intensity was selected to be 50% VO_2maximum for each individual. This enabled the children and adults to exercise at the same relative intensity and importantly, complete each of the thirty minute exercise tests. An effective temperature equal to 25°C was chosen for the two hot conditions so that the subjects did not absorb heat convectively; T_a = 31°C, 35°C.

Table 28. Wet Bulb Globe Temperature and Effective Temperature conditions chosen for the experiments in the climate chamber.

	Environmental Conditions			RH	WBGT	ET4.0
	T_a (°C)	T_w (°C)	T_g (°C)	(%)	(°C)	(°C)
Climate						
1) Hot wet	31	27	31	73	28.2	25.0
2) Hot dry	35	21	35	28	25.2	25.0
3) Neutral	22	15	22	50	17.1	14.0

WBGT = Wet Bulb Globe Temperature

ET4.0 = Effective Temperature at an air velocity of $4.0m.sec^{-1}$

PROCEDURE AND DATA COLLECTION METHODS

Anthropometry. Height was measured without shoes to the closest centimeter. Mass was measured in shorts and T-shirt for the children and shorts and singlet for the adults to the closest 0.1kg using a Sauter electronic balance accurate to ±5gms.

Skinfolds were measured and remeasured by Harpenden skinfold calipers until a repeatability within 5% was achieved. The sites utilized were triceps, mid-abdominal, thigh and calf (Katch and Katch, 1984). This approach was adopted as the sites were spread over both trunk and limbs and consequently suitable whole body estimates of subcutaneous fat were obtained.

Surface area was calculated by the Dubois method where: Surface Area (m^2) = $.00718 x wt^{0.425} x ht^{0.725}$. This method was considered adequate by Martin (1984) as it predicted the surface area to within 1.5% of the surface area carefully measured on 17 cadavers. The formula is accurate in the range of 0.8 to $2.2m^2$ but is not considered suitable for babies and very young children.

The ponderal index (*PI*) was calculated using the formula *PI* = height(cm)/cube root mass(kg). This index is an indication of the linearity of children and adults. Since both the numerator and the denominator have the same linear dimensions there is limited distortion of the ratio with an increase in size from children to adults.

Cardiovascular fitness. Cardiovascular fitness was determined by an incremental workload test on a bicycle ergometer. Heart rate was recorded via electrodes attached in the CM5 position and connected to a Hewlett Packard cardiograph. Open circuit spirometry techniques were utilized to determine all metabolic data (Consolazio, Pecora and Johnson, 1963). The subjects, with nose pegs in place, breathed through a Morgan valve which was connected to a mixing chamber via 5cm diameter lightweight tubing. Expired ventilation was measured from the outlet side of the mixing chamber by a Pneumoscan turbine ventilation meter with an estimated accuracy of ±3%. The temperature of the gas was recorded by an electronic sensor in the mixing chamber connected directly to a personal computer. A sample of gas was pumped from the mixing box at 400 ml per minute and analysed for percentage oxygen and percentage carbon dioxide by Applied Electrochemistry (S3A, CD3A) analysers. The oxygen analyser was calibrated by a known gas sample before and after the test and drifted no more than .05%. The carbon dioxide analyser was also calibrated before and after the test and drifted by no more than 0.15%. The equipment was connected via A-D converters to an IBM-Personal Computer which calculated the VO_2 and VCO_2 every thirty seconds or every minute. A Monark cycle ergometer was modified for the children with a lower adjustable seat and a one-half kilogram resistance weight so that relevant workloads could be more accurately set. Both the child and adult bicycle ergometers were statically calibrated for zero and incremental weight resistances using known calibrated weights. The protocol was developed so that a linear regression analysis could be conducted between workload and VO_2 for each individual (Table 29). The cycling cadence for both children and adults was set at 60 revolutions per minute.

Workloads were increased every two minutes up to ten minutes, and thereafter were increased every subsequent minute until volitional exhaustion. Subjects were encouraged to stand on the pedals in order to keep going for a full half minute on the last workload. Toeclips were fitted to stop their feet slipping off the pedals. The VO_2 data used for the linear regression were from the second minute in each of the first five workloads and then each minute thereafter. A linear regression of VO_2 with workload was used to predict the workloads that elicited 50% of VO_2maximum. In order that the workload could be set accurately for each thirty minute chamber test the actual workload was determined as the closest 0.25kg resistance division under the predicted 50% workload.

Table 29. Incremental workload protocol utilized for the determination of maximal oxygen uptake in children and adults.

Time (mins)	Child workload (kg)	Adult workload (kg)
1-2	0.25	0.50
3-4	0.50	1.00
5-6	0.75	1.50
7-8	1.00	2.00
9-10	1.25	2.50
11	1.50	3.00
12	1.75	3.50
13	2.00	4.00
14	2.25	4.50
15	2.50	5.00

Thermoregulation. On all testing occasions the children were dressed in shorts, shirt/T-shirt and joggers, whilst the adults wore shorts, singlet and joggers. The clothing which was weighed before and after thirty minutes of exercise was found to have absorbed no more than 5-10gms of sweat in both the 31°C and 35°C heat conditions. The subjects were exercised at 50% VO_2maximum on a bicycle ergometer for thirty minutes in a Japanese Tabai temperature and humidity chamber. The temperature was held constant to $\pm$1.0°C at 22°C, 31°C and 35°C, respectively. The humidity was held constant at 22°C but at 35°C the humidity was set at 28% and a mean drift was observed up to 39% after 30 minutes of the exercise test. At 31°C the humidity was set at 73% but exhibited a mean downward drift to 64% after thirty minutes of the exercise test. The subjects were weighed prior to and immediately after the thirty minutes of exercise in the temperature chamber on Sauter electronic scales accurate to $\pm$5 grams. On entering the chamber, ECG electrodes were placed in the CM5 position and Yellow Springs Instruments skin temperature thermisters (series 400) were placed on the outside middle of the left upper arm, on the manubrium and the middle front thigh of the left leg. The skin thermistors were taped in position with leukoflex tape. These probes had previously been calibrated in a water bath and were accurate to $\pm$0.1°C and were connected to an IBM computer via a telethermometer box. A bead thermister which had been independently calibrated in a water bath to an accuracy of $\pm$0.1°C was gradually inserted into the external ear canal; until the temperature rose above 37.0°C or the probe touched the tympanic membrane; in which case it was backed off slightly to avoid the associated pain. The ear canal was then plugged with cotton wool to reduce air movement into the canal and the lead was taped to the face to stop the probe from pulling out. The subject was connected to the metabolic system (previously described) and asked to pedal at 60 revolutions per minute and constant resistance for thirty minutes. At the start of the test a large 108cm diameter fan (Hawker Siddeley) was directed at the subject with a constant wind velocity of 4m.sec^{-1}. The fan was calibrated with a cup anemometer held over the bicycle where the subject was seated. Heart rate, oxygen uptake, skin and ear canal temperatures were sampled every five minutes. These data collection procedures were repeated at air temperatures of 22°C, 31°C and 35°C on each subject.

DATA ANALYSIS

The data was entered in a format which was suitable for analysis by the SPSSX package and a Hewlett Packard main frame computer.

The following calculations were performed so that the thermoregulatory data could be further analysed:

1. Metabolism (Watts) = 352.(0.23R + 0.77).VO_2 (Nishi, 1981) where R is the respiratory gas exchange ratio. Since R averaged 0.85 during the exercise tests, metabolism = 340xVO_2. VO_2 was averaged over the six readings recorded during the 30 minute exercise test.
2. Work rate (Watts) = work (Kgm.min^{-1})/6.12
3. Heat production (Watts) = Metabolism - Work rate
4. Metabolic Efficiency (%) = Work rate/Metabolism x 100
5. Percentage VO_2maximum = Actual VO_2/VO_2maximum x 100
6. Evaporative Mass loss (gms.hr^{-1}) = Mass loss x 2 - respiratory mass loss- metabolic mass loss
   E = 2.Mass loss- 60.(0.034 -0.006P_a).V -0.18VO_2.60
   where P_a = Water Vapour Pressure (KPa), V = Ventilation Rate (l.min^{-1}). (Kerslake, 1972)

7. Evaporative heat loss index (EHLI)

EHLI = Evaporative mass loss/heat production

8. Mean skin temperature(T_s) = $0.5T_c + 0.36T_t + 0.14T_a$ (Grucza, 1982)

where T_c = temperature chest; T_t = temperature thigh and T_a = temperature arm.

9. Percentage of maximum heart rate = heart rate/heart rate maximum x 100.

10. Heart rate index = percentage of maximum heart rate/percentage of VO_2maximum.

The following statistical analyses were performed on the HP computer.

A. In order to establish whether significant differences existed between the groups an Anova by sex and status (2 x 2 format) was performed for the sum of skinfolds, surface area/mass, heart rate max, VO_2maximum, ponderal index and work rate in the climate chamber.

B. The differences between the groups exercising in the three environments was examined by a multivariate analysis of variance technique. Manova by status and climate (2 x 3 format) were performed for % VO_2maximum, Metabolic Efficiency, Relative Heat Production, Relative Evaporative Mass loss and the Evaporative heat loss index. This analysis was generally repeated separately for the male and female subjects in the study.

C. The differences between the groups exercising for thirty minutes in the three environments was examined by a multivariate analysis of variance technique. Manova by status, climate and time (2 x 3 x 6 format) were performed on ear canal temperature, mean skin temperature, heart rate, percentage maximum heart rate, heart rate index and oxygen uptake. This analysis was generally repeated separately for the male and female subjects in the study.

D. The possible reasons for the differences between the groups was examined by an analysis of covariance. The variables used as covariates in the analysis were:

i) The sum of skinfolds.

ii) The surface area/mass ratio.

iii) The VO_2maximum.

PART B: CHILDREN AND ADULTS EXERCISING IN HOT WET CLIMATIC CONDITIONS WITH DIFFERENT LEVELS OF RADIANT HEAT

RESEARCH DESIGN

The purpose of part B of the study was to compare the physiological and thermoregulatory responses of children and adults exercising in hot wet conditions with varying levels of radiant heat and varying levels of metabolism. This part of the research was conducted with two different designs.

1. The first condition examined the physiological and thermoregulatory responses of children and adults exercising at 50% VO_2maximum and two levels of radiant heat. The research design utilized a three way analysis of variance with the discrete variable of status (child, adult) and repeated measures on level of radiant heat (low, high) and repeated measures over time (6 levels). The independent variables involved in this design were:

Status - male child and male adult.

Radiant heat - low and high.

Time - repeated measures on the subjects at 5 minute intervals during the thirty minutes of the test.

2. The second condition examined the physiological and thermoregulatory responses of children and adults exercising under two levels of radiant heat and increasing levels of metabolism. This research design utilised a three way analysis of variance with the discrete variable of status (child, adult) and repeated measures on levels of radiant heat (low, high) and repeated measures of increasing levels of metabolism (low, medium, high). The independent variables involved in this design were:

Status - male child and male adult.

Radiant heat - low and high.

Metabolism - repeated measures of ten minutes of exercise at approximately 35%, 50% and 65% of VO_2maximum.

SUBJECTS

Ten male undergraduate physical education students from Victoria University of Technology volunteered for the adult group of the study. Informed consent and approval of the Victoria University of Technology Ethics Committee were obtained prior to the commencement of the study. The students participated in weekly human movement classes and were not considered to be elite level athletes.

Ten male students from grades four, five and six at Ascot Vale Primary School volunteered for the children's group after approval was given by the School Council and the Victoria University of Technology Ethics Committee and a consent form was signed by their parents. The children all played school sport but none were considered to be elite or highly trained athletes.

Since all of the subjects were from Melbourne and the study was conducted in the cooler months of the year, none of the subjects were deemed to be acclimatized to exercising in the hot wet conditions with radiant heat established in the climate chamber.

RATIONALE FOR THE CHOICE OF TESTS

Anthropometric tests. Measurements were taken of the variables considered by the researcher as likely to affect temperature regulation. The rationale for test selection were the same as for those discussed in part A of the study (page 42).

Cardiovascular fitness test. Cardiovascular fitness was measured by an incremental workload to maximum protocol on a bicycle ergometer with volitional termination of the test by the subjects.

Thermoregulatory tests with radiant heat and constant metabolism. Two exercise tests of 30 minutes duration were conducted on a bicycle ergometer in the environmental conditions as detailed in Table 30. Both tests were preceded by 10 minutes of exercise in the climate chamber without the radiant heat. This preliminary 10 minutes adjusted the subjects to exercise in the heat so that the physiological and thermoregulatory responses due to the addition of either high or low levels of radiant heat could be evaluated. The conditions were chosen to simulate the hot wet conditions including radiant heat which often occur in Australia. The air velocity of 4.0m.sec^{-1} is the average wind speed recorded in Australia's State Capital Cities (Bureau of Meteorology, 1979). The exercise intensity was selected to be 50% VO_2 maximum for each individual. This enabled the children and adults to exercise at the same relative intensity and complete each of the forty minute exercise tests. The purpose of this experiment was to ascertain the physiological and thermoregulatory differences between children and adults when they exercised at the same relative intensity in radiant heat.

Table 30. Wet Bulb Globe Temperature and Corrected Effective Temperature conditions chosen for the experiments in the climate chamber.

	Environmental Conditions			RH	WBGT	CET4.0
	T_a	T_w	T_g			
Climate	(°C)	(°C)	(°C)	(%)	(°C)	(°C)
1) Hot wet low radiant	31	27	37	73	28.8	28.0
2) Hot wet high radiant	31	27	49	73	30.0	31.5

WBGT = Wet Bulb Globe Temperature

CET4.0 = Corrected Effective Temperature at an air velocity of 4.0m.sec^{-1}

Thermoregulatory tests with radiant heat and increasing metabolism. Two bicycle ergometer exercise tests, each at three levels of metabolism (approximately 35%, 50% and 65% VO_2maximum) were conducted under two different radiant heat loads. Both exercise tests lasted 30 minutes with 10 minutes at each level of metabolism. This experiment was conducted in the environmental conditions as detailed in Table 30. The purpose of this experiment was to ascertain the physiological and thermoregulatory differences between children and adults when metabolism is increased under radiant heat stress. The upper metabolic level of 65% was chosen because this appears to be close to the maximum that athletic children can maintain for up to one hour in neutral climatic conditions (Davies, 1979).

PROCEDURE AND DATA COLLECTION METHODS

Anthropometry. Height, mass, and skinfolds were measured by the same methods previously described in part A (page 43). The surface area to mass ratio and the ponderal index were also calculated by the methods described earlier (page 43).

Cardiovascular fitness. The protocol and open circuit spirometry techniques as reported in part A were used to gather the metabolic data. Heart rate was measured by a Polar PE 3000 sportstester rather than an electrocardiogram machine. The workload which elicited 50% of VO_2maximum was calculated by the linear regression method (page 44).

Thermoregulation with radiant heat and constant metabolism. Both the children and adults wore shorts and joggers in the two 40 minute exercise tests conducted under hot wet conditions. The subjects exercised on a bicycle ergometer at a workload calculated to elicit 50% of VO_2maximum. The trunk was left bare for direct radiant heat exposure to the back and left side. The first 10 minutes of the test was conducted at an air temperature of 31°C and high humidity (77±6%) in a Tabai temperature and humidity chamber. Two 60cm strip radiators were switched on after the initial 10 minutes of exercise. One was directed at the back and set at a distance of 55cm from the body and the other, positioned at right angles to the first was directed at the left side of the body and also set at a distance of 55cm. The bars of the radiators were aligned to be parallel to the subject's trunk while he was sitting on the seat of the bicycle ergometer. The heat output from the radiators was made variable by the attachment of a resistor. The resistor was adjusted to maintain either a black bulb temperature (T_g) equal to 37°C or a black bulb temperature equal to 49°C. The black bulb temperature was measured by a 12cm black bulb thermometer set at shoulder height. These radiators gradually increased the air temperature and reduced the humidity within the climate chamber despite the maximum effort by the environmental chamber to maintain the setting. In the low radiant heat experiment the air temperature increased from 31°C to 32°C and the relative humidity decreased from 77±6 to 72±3%. In the high radiant heat experiment the air temperature increased from 31°C to 34°C and the relative humidity decreased from 77±6 to 66±2%. A 108cm diameter fan was directed at the trunk and face with an air velocity of 4.0m.sec^{-1} for the duration of the tests. The subjects were weighed on Sauter electronic scales accurate to ±5grams before going into the climate chamber and immediately after 40 minutes of exercise. A sports tester was fitted before entering the chamber to measure heart rate at 5 minute intervals during the test. A small thermister previously calibrated to ± 0.1°C was gradually inserted into the external ear canal until the temperature rose above 37.0°C or touched the tympanic membrane; in which case it was backed off slightly to avoid the associated pain. The ear canal was then plugged with cotton wool to reduce air movement into the canal and the lead was taped to the face in a way which stopped the probe from pulling out of the ear. This thermister was connected to an IBM computer via a telethermometer box so that the ear canal temperature could be measured at five minute intervals during the exercise test. The subject was also connected to a metabolic system (previously described) and asked to pedal at 60 revolutions per minute and at a constant resistance for 40 minutes. Oxygen uptake was recorded every five minutes during the test. Five skin temperature sites were measured by a hand held infrared surface thermometer (Everest Interscience) accurate to ±0.5°C. Three of the sites; lower right back, lower left back and left upper arm at the level of the medial deltoid muscle indicated skin temperatures exposed to radiant heat and two of the sites; right upper arm at the level of the medial deltoid and the cheek one centimeter below the left orbit of the eye indicated skin temperatures not exposed to radiant heat. The thermometer recorded skin temperature instantaneously when pointed at the skin. Temperature probes could not be used because they would have been heated up more than the skin by the radiators. The five skin sites were sampled at five minute intervals during the exercise test. A dew point sensor (Beckman) connected to a $12cm^2$ capsule was used to measure the humidity in the climate chamber at ten minute intervals during the exercise test.

Thermoregulation with radiant heat and increasing metabolism. These tests adopted the same environmental conditions to that described previously for hot wet conditions with radiant heat except that the subjects exercised on the bicycle ergometer for a total of thirty minutes at 60 revolutions per minute. This thirty minutes of exercise comprised ten minutes exercising at approximately 35% VO_2maximum, ten minutes exercising at approximately 50% VO_2maximum and ten minutes exercising at approximately 65% VO_2maximum. The experiment was carried out at low (T_g= 37°C) and high (T_g = 49°C) radiant heat loads with the climate controls set at T_a = 31°C and humidity equal to 73%. The effect of the radiant heaters resulted in an increase in air temperature from 31°C to 32°C in the low radiant heat and from 31°C to 34°C in the high radiant heat experiment. The humidity was maintained at a high level but decreased during the thirty minutes from 82±8% to 72±2% in the low radiant heat and from 72±3% to 68±4% in the high radiant heat experiment. Skin temperatures and ear canal temperatures were collected at five minute intervals as previously described. In order to calculate sweat rate body mass was recorded before and immediately after thirty minutes of exercise on Sauter electronic scales accurate to ±5grams. Metabolism and heart rates were also recorded at five minute intervals. Humidity of the chamber was recorded at ten minute intervals throughout the experiment (5,15 and 25minutes respectively) by a Beckman dew point sensor.

DATA ANALYSIS

The data was entered in a format which was suitable for analysis by the SPSSX package and a Hewlett Packard main frame computer. The following calculations were performed so that the thermoregulatory data could be further analysed.

1. Metabolism (Watts) = 340 x VO_2 (litres). Metabolism was averaged over the eight readings of the exercise test for the 50% effort tests and was averaged over the ten minutes at each level of the increasing metabolism tests. The metabolism was also reported as an actual percentage of VO_2maximum for each individual for each test and at each level of metabolism.
2. Rate of Work (Watts) = work ($kgm.min^{-1}$)/ 6.12
3. Heat Production (Watts) = Metabolism - Work rate
4. Metabolic Efficiency (%) = Work rate/Metabolism x 100

5. Sweat rate ($g.hr^{-1}$) = weight loss/test duration in minutes x 60. Evaporative weight loss was not calculated because large beads of sweat formed on the forehead and back of the irradiated subjects and an unknown portion of sweat dripped on the floor. The air velocity of $4 m.sec^{-1}$ generated from the fan did not ensure evaporation of all of the large beads of sweat.

6. Sweat heat loss index (SHLI) was calculated to represent the sweat lost in proportion to the heat produced by the body.

   SHLI = sweat rate/heat production

7. Mean skin temperature was represented by the average of the three radiant skin sites (lower right back, lower left back, upper left arm) and the average of the two non-radiant skin sites (upper right arm and cheek).

8. Humidity in the chamber was measured by calculating the partial pressure of water vapour using the formula

   $P_a = 13.3 - .605\, T_{dp} + .0411\, (T_{dp})^2$ where T_{dp} is the dew point temperature of the air in the chamber.

   Relative humidity = $P_a / P_s \times 100$

9. Percentage of maximum heart rate = heart rate/ heart rate maximum x100.

10. Heart rate index = percentage of maximum heart rate/percentage of VO_2maximum.

The following statistical analyses were performed on the HP computer.

A. In order to establish whether significant differences existed between the groups a univariate analysis of variance was performed for the sum of skinfolds, surface area/mass, heart rate max, VO_2maximum and ponderal index.

B. The differences between the groups exercising in the constant metabolism condition was examined by a multivariate analysis of variance technique. Manova by status, radiant heat and time (2 x 2 x 6 format) were performed for oxygen uptake, mean temperature of skin exposed to the radiant heat, mean temperature of the skin not exposed to the radiant heat, ear canal temperature, heart rate, percentage of maximum heart rate and heart rate index. Also the preliminary 10 minutes of exercise without the radiant heat was analysed by a multivariate analysis of variance technique. Manova with a 2 x 2 x 2 format were performed for the previous six dependent variables.

C. The differences between the groups exercising in the constant metabolism condition was examined by a multivariate analysis of variance technique. Anova by status and radiant heat (2 x 2 format) were performed for rate of work, mean metabolism, heat production, relative heat production, percentage of maximum oxygen uptake, sweat rate, relative sweat rate and sweat heat loss index.

D. The differences between the groups exercising in the increasing metabolism condition was examined by a multivariate analysis of variance technique. Manova by status, radiant heat and time (2 x 2 x 6 format) were performed for oxygen uptake, mean temperature of skin exposed to the radiant heat, mean temperature of the skin not exposed to the radiant heat, ear canal temperature, heart rate, percentage of maximum heart rate and the heart rate index.

E. The differences between the groups exercising in the increasing metabolism condition was examined by a multivariate analysis of variance technique. Manova by status, radiant heat and level of metabolism (2 x 2 x 3 format) were performed for rate of work, mean metabolism, heat production, relative heat production, percentage of maximum oxygen uptake, sweat rate, relative sweat rate and sweat heat loss index.

F. The possible reasons for the differences between the groups was examined by an analysis of covariance. The variable used as a covariate in this analysis was the surface area/mass ratio. The level of significance, $\alpha = .05$ was adopted for all statistical tests.

CHAPTER FOUR

RESULTS

PART A: CHILDREN AND ADULTS EXERCISING IN HOT WET AND HOT DRY CLIMATIC CONDITIONS WITHOUT RADIANT HEAT

The purpose of Part A of the study was to compare the physiological and thermoregulatory responses of children and adults exercising in hot wet and hot dry environmental conditions without radiant heat. Baseline data was established in a neutral climate to see if children and adults responded differently in the two hot climates. Generally the analysis was performed separately for males and females due to the female children significantly decreasing the percentage of VO_2 maximum at which they worked in comparison to the female adults in the hot climatic conditions. The results of the experiments are presented in sections as follows:

1. Subjects' characteristics
2. Work rate and metabolism
3. Heart rate responses
4. Evaporative heat loss responses
5. Mean body temperatures
6. Covariates; Skinfolds, SA/Mass, VO_2 maximum

1. SUBJECTS' CHARACTERISTICS

HEIGHT, MASS AND AGE

The subjects' characteristics are presented in Table 31. The mean age of the prepubertal children was 10.2 years. Both groups were 143 cms tall and 37.0 kg and 40.8 kg for the males and females, respectively. The female children were 86% of the height of their adult controls and 72% of their mass. The male children were 79% of the height of their adult controls and 48% of their mass.

SURFACE AREA/MASS

There was a significant difference for the surface area/mass ratio between the child and adult groups (Table 31). The male children had a 31.6% greater surface area to mass ratio than the male adults whilst female children had an 8.3% greater surface area/mass than their adult counterparts. The significant interaction between sex and status (Appendix C-1) indicated that the difference between the two male groups was greater than the difference between the two female groups.

PONDERAL INDEX

A significant interaction existed between the groups on the calculation of the ponderal index (Table 31).

The male adults were 2.1% less than the male children and the female adults were 4.1 % greater than the female children (Appendix C-1). There were no main effects for either status or sex.

Table 31. Physical and physiological characteristics of the subjects.

Characteristics Males	Children	Adults
Age (yr)	[1]10.2±0.92[2]	21.3±1.0
Height (cm)	143±11.5	180±6.8
Mass (kg)	37.0±11.1	76.4±7.3
SA/Mass ($cm^2 \cdot kg^{-1}$)#	337±40.6	256±11.6
Ponderal Index	43.3±2.4	42.4±1.2
Sum skinfolds (mm)#*	51.2±19.0	29.5±7.2
$\dot{V}O_2$ max ($ml.kg^{-1}.min^{-1}$)#*	53.1±4.6	58.7±6.5
Heart Rate max ($b.min^{-1}$)	197±7.0	193±6

Characteristics Females	Children	Adults
Age (yr)	10.3±1.0	20.1±0.9
Height (cm)	143±8.5	166±5.6
Mass (kg)	40.8±6.9	56.4±7.9
SA/Mass($cm^2 \cdot kg^{-1}$)#	314±21.8	289±21.5
Ponderal Index	41.7±1.2	43.4±1.7
Sum skinfolds(mm)#*	67.5±20.4	56.6±23.2
VO_2max ($ml.kg^{-1}.min^{-1}$)#*	44.1±7.9	48.2±8.0
Heart Rate max ($b.min^{-1}$)	196±10	189±8

Significant difference between children and adult groups

* Significant difference between male and female groups

[1] = mean   [2] = standard deviation

SUM OF SKINFOLDS

There was a significant difference between the adult and child groups for the sum of skinfolds (Appendix C-1). The male children's skinfold sum was 73.5% greater than the male adults. The female children's group was 19.3% greater than the female adult group (Table 31). There was also a significant difference between the sexes; with the female groups having higher skinfold sums than those of the male groups.

MAXIMUM OXYGEN UPTAKE

VO_2 maximum was significantly different between the sexes (Table 31) with the female groups demonstrating lower values than the male groups. There was a statistically significant difference at p = .055 between the child and adult groups (Appendix C-1). The male adult group had a 10.5% higher VO_2 maximum than the male child group. The female adult group had a 10.9% higher VO_2 maximum than the female child group.

HEART RATE MAXIMUM

Heart rate maximum recorded on the bicycle ergometer during the maximal oxygen uptake test did not significantly differ between the groups (Appendix C-1). However, the childrens' groups maximum heart rates did tend to be higher than the adult groups. The male children's group averaged 4 $bts.min^{-1}$ higher than the male adult group. The female children's group averaged 7 $bts.min^{-1}$ higher than the female adult group (Table 31).

2. WORK RATE and METABOLISM

WORK RATE

The work rate was calculated from the VO_2 maximum test by linear regression and was predicted to be at 50% of VO_2 maximum (Table 32). The adult groups' work rates were significantly greater than the childrens groups (Appendix C-1). The male adult work rate was approximately three times greater than the male child work rate (Table 32). The female adult work rate was just less than three times greater than the female child work rate. There was also a significant difference between the sexes for work rate. The male groups' work rates were greater than the female groups'.

Table 32. Work rate for the three 30 minute climate chamber tests.

Status	Sex	Work rate (watts)
Children#	Male*	[1]41±13[2]
	Female	31±7
Adults	Male*	139±20
	Female	86±10

Significant difference between the child and adult groups.

* Significant difference between the male and female groups.

[1] = mean [2] = standard deviation

AVERAGE METABOLISM

Since the work rate was kept constant over the 30 minutes of the exercise test; the six oxygen uptake samples taken at 5 minute intervals were averaged and converted to metabolism (watts).

Male

The adult group utilized more than double the metabolism of the children (Table 33). There were no significant differences for the metabolisms between the three climates (Appendix C-2).

Female

There was a significant difference between the child and adult groups with the adults requiring a little less than double the metabolism of the children (Table 33). Similar to the males there was no significant difference for metabolism between the three climates (Appendix C-2).

Table 33. Average metabolism for the male and female groups in the three climates.

Group	Metabolism 22°C	Metabolism 31°C	Metabolism 35°C
MALES			
Child#	[1]323±85[2]*	309±71	326±85
Adult	740±130	734±110	724±107
FEMALES			
Child#	285±53	260±46	268±43
Adult	477±33	481±35	479±37

Significant difference between the adult and children groups * units = watts

[1] = mean [2] = standard deviation

AVERAGE METABOLISM AS A PERCENTAGE OF VO_2 MAXIMUM

Total sample

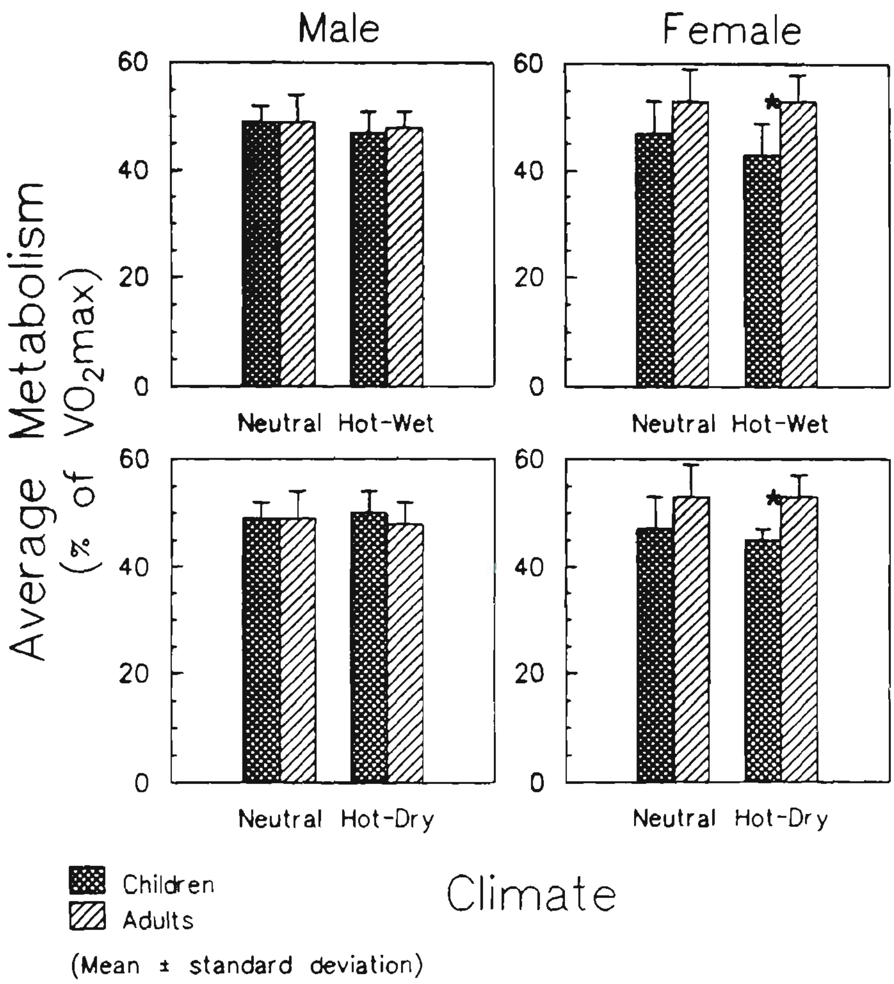
Figure three demonstrates that there was a significant interaction between status and sex (Appendix C-2). No significant difference was observed between the two male groups for the percentage of VO_2 maximum at which they exercised while the female children exercised at a significantly lower percentage of VO_2 maximum than the female adults. Since the two female groups performed at different relative efforts they were subsequently analysed separately to the male groups.

Male

Figure three displays no significant differences in $\%VO_2$ maximum between the child and adult groups (Appendix C-2). Also there were no significant differences in $\%VO_2$ maximum between the three climates.

Female

Figure three also exhibits a significant difference in $\%VO_2$ maximum between the female child and adult groups (Appendix C-2). There was also a significant interaction between climate and group; with the children's group exercising at a significantly lower $\%VO_2$ maximum than the adult group in the hot wet and hot dry climates and a similar $\%VO_2$ maximum in the neutral climate.



* significant difference between the children and adult groups

Figure 3. Average metabolism as a percentage of VO_2 maximum in the hot and neutral climates without radiant heat.

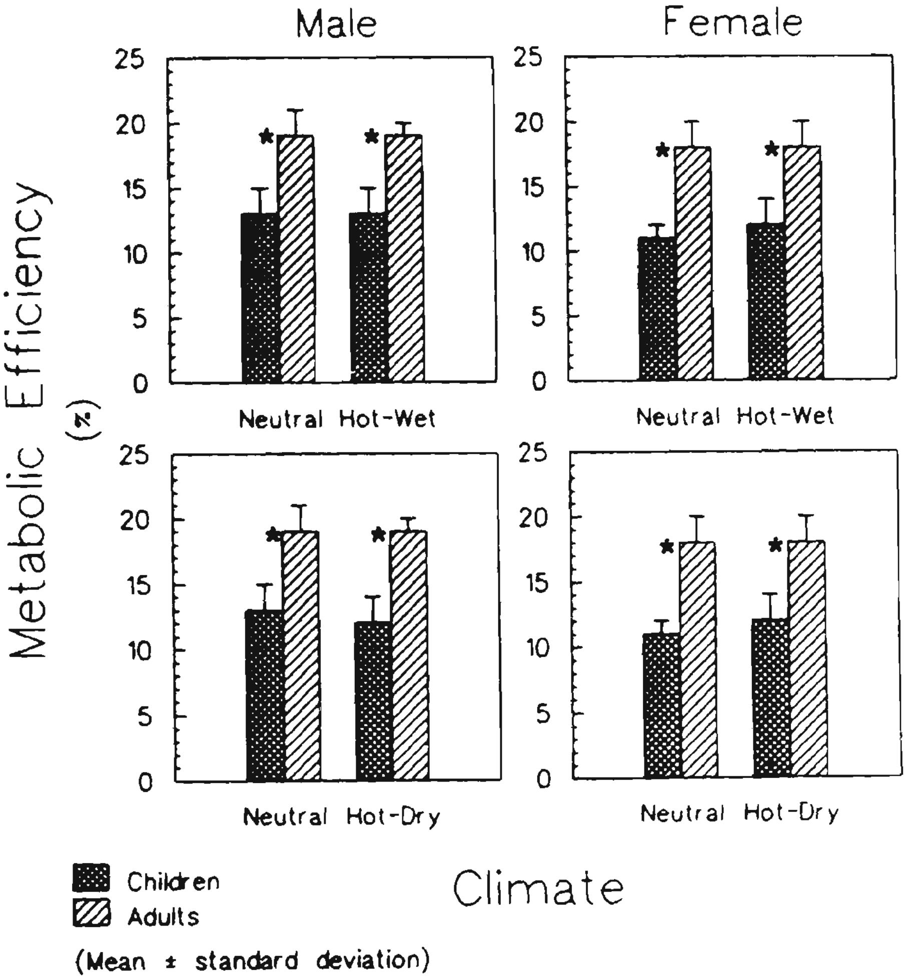
METABOLIC EFFICIENCY

Male

The metabolic efficiency data as presented in Figure four displays a significant difference between the child and adult group (Appendix C-2). The male children's group had a metabolic efficiency close to 13% and the male adult group had a metabolic efficiency averaging 19% (Appendix A-2). There was no significant effect due to climate.

Female

Figure four also displays a significant difference between the female groups (Appendix C-2). The female children's group had a metabolic efficiency close to 12% and the female adult group had a metabolic efficiency averaging 18% (Appendix A-2). There was no significant effect due to climate.



* significant difference between the children and the adult groups

Figure 4 Metabolic efficiency in the hot and neutral climates without radiant heat.

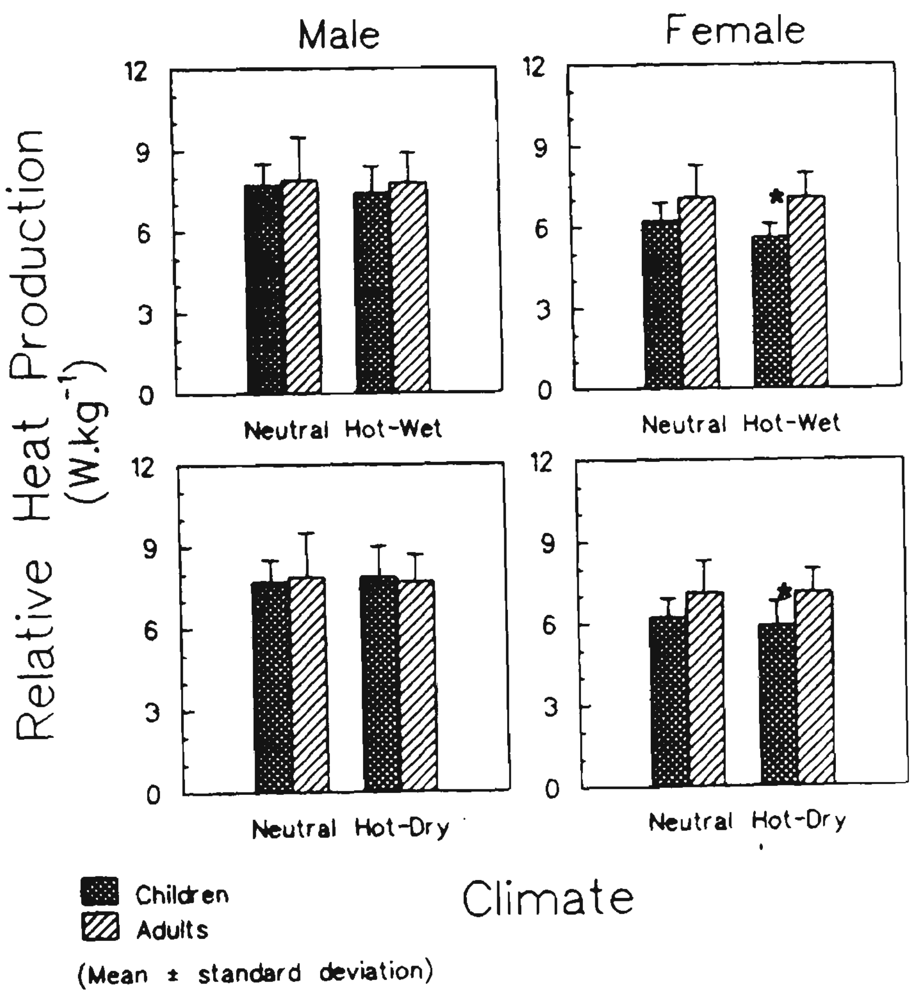
HEAT PRODUCTION

Male

Figure five indicates there was no significant difference between the two groups for relative heat production (Appendix C-3). The male children's mean heat production was 7.7 $W.kg^{-1}$ and the adults was 7.9 $W.kg^{-1}$ (Appendix A-3). There were no significant differences between the three climates.

Female

Figure five demonstrates a significant difference between the female groups for relative heat production (Appendix C-3). The children's group generated 1.4 $W.kg^{-1}$ less heat than the adult group in the two hot climates but produced a similar amount in the neutral climate (Appendix A-3).



* significant difference between the children and adult groups

Figure 5 Relative metabolic heat production in the hot and neutral climates without radiant heat.

OXYGEN UPTAKE

Male

There was no significant difference between the adult and child groups for oxygen uptake over the 30 minutes of the exercise test (Appendix C-3). However, there was a trend for the children to be exercising at a lower VO_2 during the test (Figure 6). The adult's VO_2 was between 1 to 4 $ml.kg^{-1}.min^{-1}$ higher than that of the children in the three climates and over the duration of the test (Appendix A-6). Additionally, there was a significant increase in the oxygen uptake of both groups over time (Appendix C-3). This amounted to a 1 to 2 $ml.kg^{-1}.min^{-1}$ increase in VO_2 over the duration of the test.

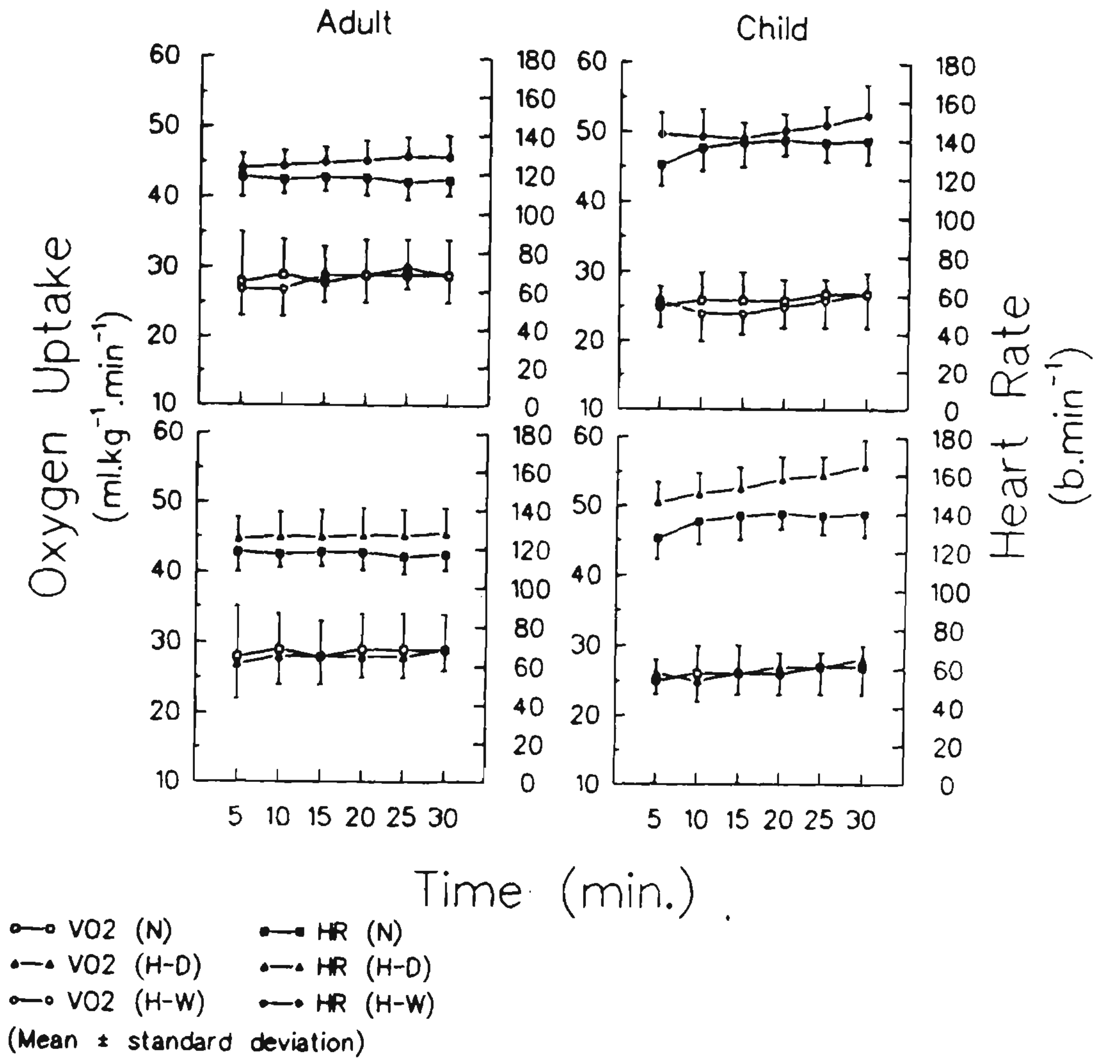


Figure 6 Oxygen uptake and heart rate for males in the hot and neutral climates without radiant heat.

OXYGEN UPTAKE

Female

Figure seven illustrates the significant difference in oxygen uptake between the adult and child groups (Appendix C-3). The children were working at a VO_2 which was between 4 and 7 ml.kg^{-1}.min^{-1} lower than those of the adults. There were no significant differences in oxygen uptakes between the climates or over time within each climate.

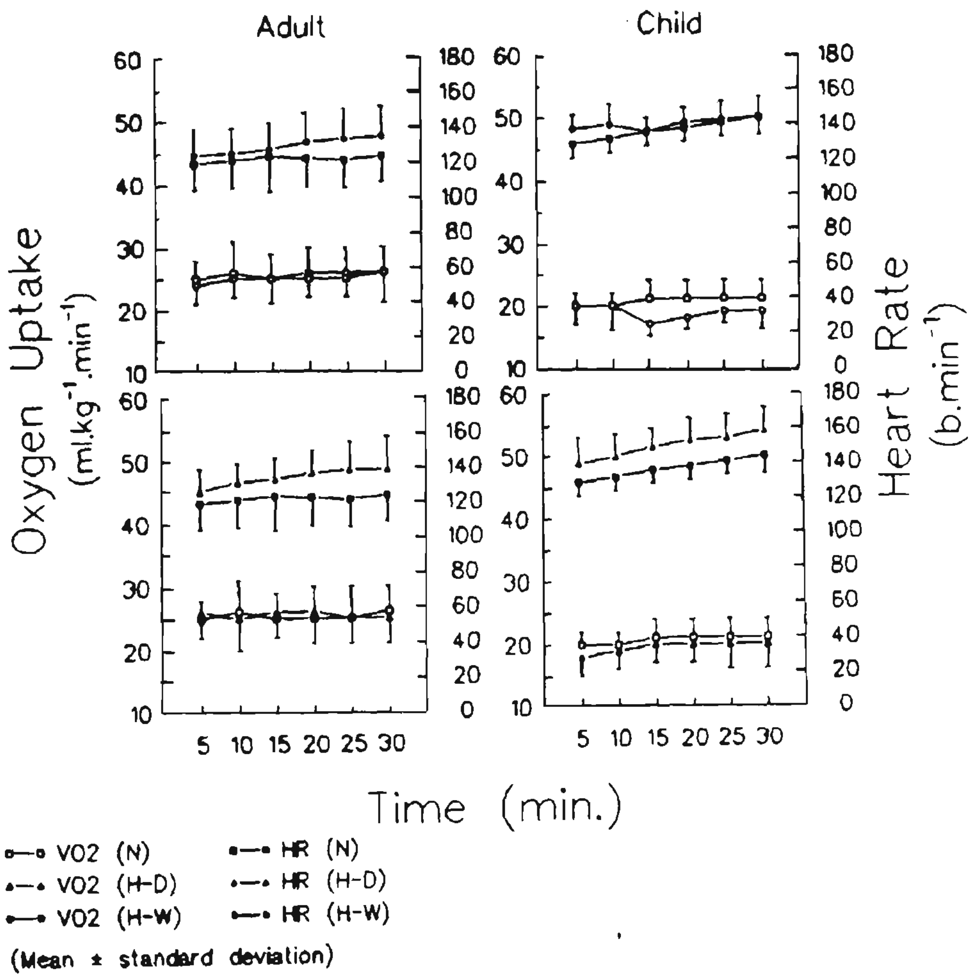


Figure 7 Oxygen uptake and heart rate for females in the hot and neutral climates without radiant heat.

3. HEART RATE RESPONSES

HEART RATE

Male

Figure six illustrates the significantly higher heart rate for the children's group compared to the adult group over the 30 minutes of the exercise tests (Appendix C-3). There was also a significant increase in heart rate over time. In the neutral climate the children's heart rates increased from 127 $bts.min^{-1}$ to 140 $bts.min^{-1}$ compared to the adults who remained at 118 $bts.min^{-1}$ for the 30 minutes of exercise (Appendix A-9). The children's group also increased their heart rates significantly more than the adult group when they moved from the neutral climate into the two hotter climates as demonstrated by the status by climate interaction (Appendix C-3). The children's heart rate at 5 minutes increased from 127 $bts.min^{-1}$ to 143 and 146 $bts.min^{-1}$ in the hot wet and hot dry climates, respectively. The adult's heart rate at the same time period increased from 118 $bts.min^{-1}$ to 123 and 125 $bts.min^{-1}$ in the two hot conditions, respectively. At 30 minutes the children's heart rate increased from 140 $bts.min^{-1}$ to 143 and 165 $bts.min^{-1}$ in the hot wet and hot dry climatic conditions, respectively. At the same time period the adult's heart rate increased from 117 $bts.min^{-1}$ to 129 and 128 $bts.min^{-1}$ in the same two hot conditions, respectively (Appendix A-9).

Female

Figure seven illustrates the significantly higher heart rate of the children's group in comparison to the adult group (Appendix C-3). This occurred despite the children exercising at a lower $\%VO_2$ maximum than the adults. There was also a significant increase in heart rate over time. In the neutral climate the children's group increased from 130 $bts.min^{-1}$ after 5 minutes to 144 $bts.min^{-1}$ after 30 minutes of exercise. In the same conditions the adult group increased from 120 $bts.min^{-1}$ to 124 $bts.min^{-1}$ (Appendix A-9). The children had a significantly higher heart rate than the adults in the neutral (p=.058) and hot dry climate (p=.053) and a similar heart rate in the hot wet climate (Appendix C-3). Despite exercising at a significantly lower $\%VO_2$ maximum than the adult group in the hot dry conditions the children's heart rates were 14 bts and 20 bts higher at 5 minutes and 30 minutes of exercise, respectively (Appendix A-9).

PERCENTAGE OF HEART RATE MAXIMUM

Male

The analysis of the percentage of heart rate maximum results had a similar response to the absolute heart rate results (Appendix C-3). Figure eight indicates that the children's group was exercising at a significantly higher percentage of heart rate maximum than the adult group in all three climate conditions and this trend appeared to be more accentuated after 30 minutes of exercise. After this time interval the children's group recorded heart rates which were 70%, 77% and 83% of heart rate maximum in the 22°C, 31°C and 35°C climates, respectively. Similarly, the adult group recorded heart rates which were 60%, 66% and 66% of heart rate maximum in the 22°C, 31°C and 35°C climates, respectively. The children's percentage of heart rate maximum had increased significantly more from neutral to hot conditions than the adults (Appendix C-3). This difference in % heart rate maximum appeared to be most evident between the neutral and hot dry conditions with a 13% increase in the final percentage of heart rate maximum for the children and a 6% increase for the adults (Appendix A-10).

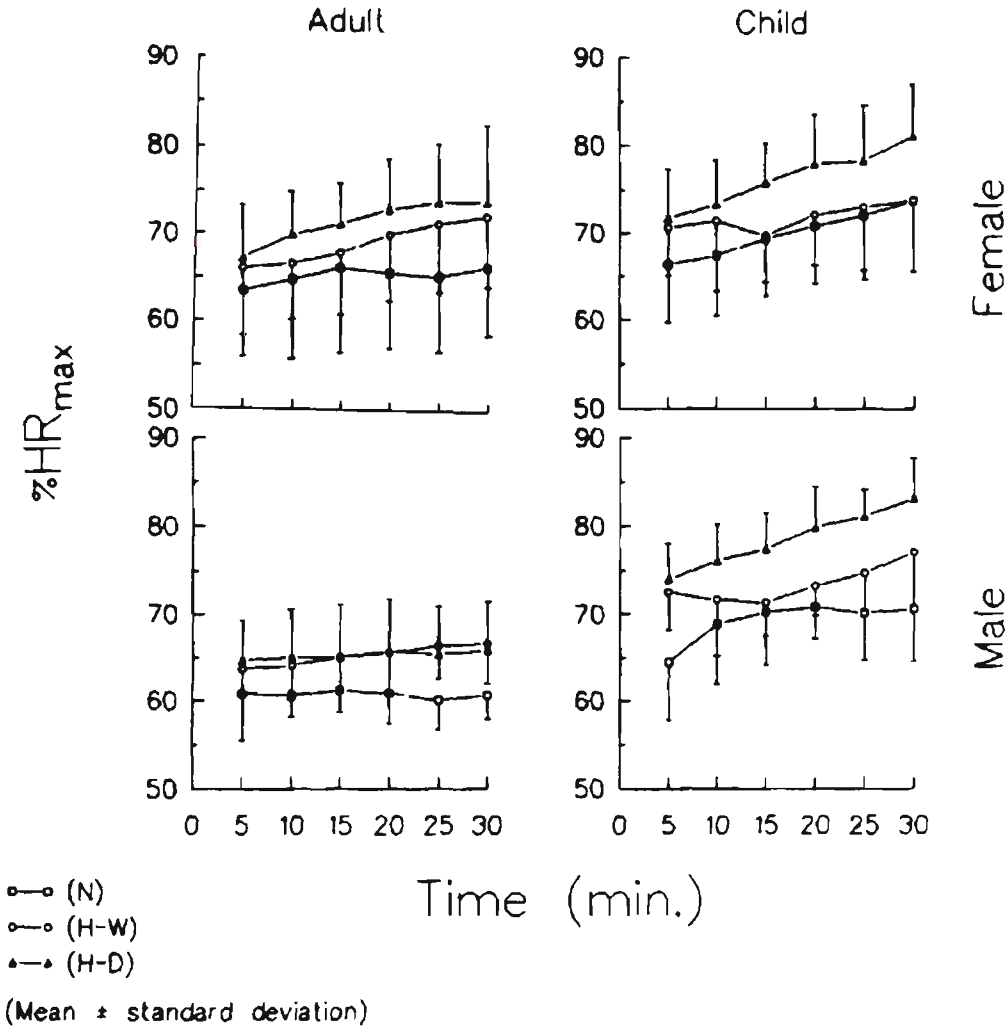


Figure 8 Percentage of heart rate maximum in the hot and neutral climates without radiant heat for the 30 minute exercise test.

Female

Figure eight illustrates similar values for the % heart rate maximum between the adult and child groups (Appendix A-10). There were no significant differences between the groups (Appendix C-3). Figure eight also illustrates a significant increase in the percentage of heart rate maximum over time. After 30 minutes of exercise the children's group increased from 66% after 5 minutes to 74% of heart rate maximum in 22°C; from 71% to 74% of heart rate maximum in 31°C and from 72% to 81% heart rate maximum in 35°C. Similarly, the adult group increased from 63% to 66% of heart rate maximum in 22°C; from 66% to 72% of heart rate maximum in 31°C and from 67% to 73% of heart rate maximum in 35°C (Appendix A-10).

HEART RATE INDEX

The heart rate index was calculated as the percentage of heart rate maximum divided by the percentage of VO_2 maximum. This index standardized the heart rate response in proportion to the exercising percentage of maximum oxygen uptake.

Male-Female

In both the males and females there was a significant difference for the heart rate index between the adult and children groups (Appendix C-4). Figure nine illustrates the higher heart rate index of the children in comparison to the adults for the 30 minutes of the exercise tests. This difference was statistically significant in the two hot climates. In both the hot wet and hot dry conditions the male children's mean heart rate index (1.56) was 14% higher than the adults (1.37). Also in the two hot conditions the female children's mean heart rate index (1.69) was 27% higher than the female adults (1.33) (Appendix A-11). The children also appeared to increase their heart rate index more than the adults during the 30 minutes of the exercise test but there were no significant differences between the groups as both increased over time by a similar amount (Appendix C-4).

Total sample

Since there appeared to be no difference in the results of the separate analyses for the male and female groups it was appropriate to reanalyse the data using a 4-way MANOVA to see if there was any significant difference between the sexes. There were no significant differences between the male and female groups (Appendix C-4). Similar to the individual analyses for each sex there were significant main effects for climate and time. The heart rate index increased in the hot wet and hot dry climates in comparison to the neutral climate and also increased over the 30 minutes of the exercise test. There were also two significant interactions that did not appear in the smaller analyses (Appendix C-4). There was a significant Time by Climate interaction with a greater drift in the heart rate index over time in the hotter climates in comparison to the neutral climate. Also the children drifted significantly more on the heart rate index over time in the two hot climates than the adults. Taken as an average over the two hot climates the children drifted on the heart rate index by 0.14 which was double that observed in the adults who drifted by 0.07 (Appendix A-11).

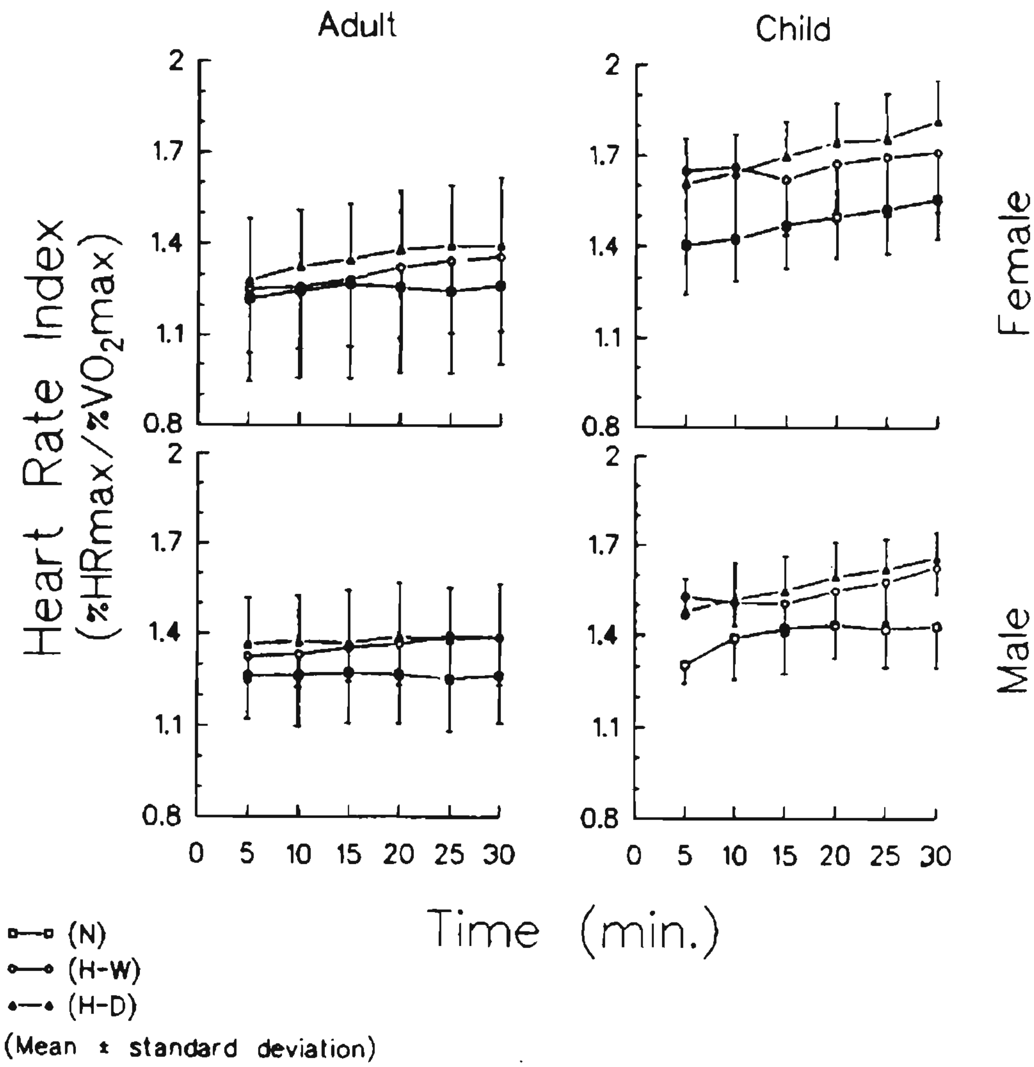


Figure 9 Heart rate index in the neutral and hot climates without radiant heat for the 30 minutes of the exercise test.

4. EVAPORATIVE HEAT LOSS RESPONSES

EVAPORATIVE MASS LOSS

It was demonstrated that the adult groups had a greater absolute evaporative weight loss than the children's groups for all three climates (Table 34). There was also a significant difference between the three climates with the two hot climates producing a much greater absolute evaporative weight loss than the neutral climate.

Table 34 Absolute evaporative mass loss for children and adults

Climate	Status	Mass loss ($gm.hr^{-1}$)
Males		
22°C^	Child#	[1]162±77[2]
	Adult	471±134
31°C^	Child#	301±102
	Adult	877±215
35°C^	Child#	344±144
	Adult	1068±207
Females		
22°C^	Child#	61±32
	Adult	148±49
31°C^	Child#	224±91
	Adult	376±112
35°C^	Child#	305±125
	Adult	605±209

significant difference between adult and children's groups

^ significant difference between climates

[1] = mean [2] = standard deviation

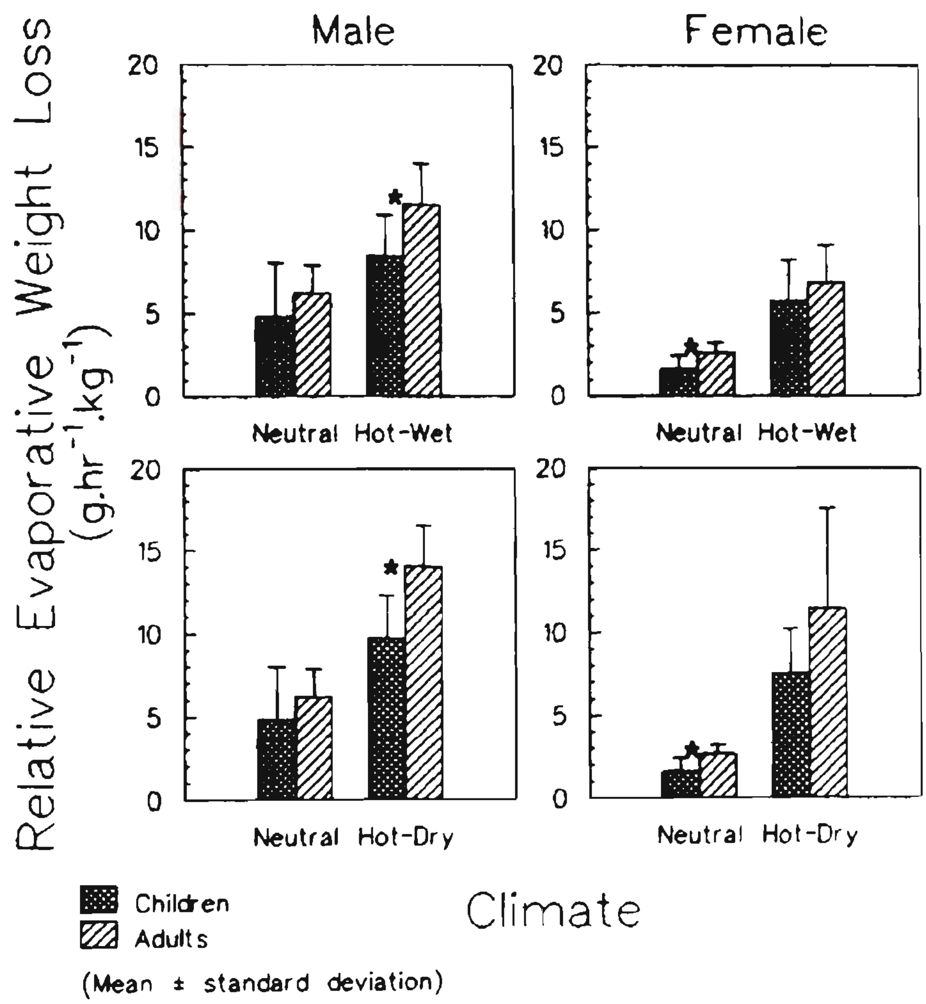
To compare the evaporative weight loss between children and adults the amount of water evaporated per kg of body mass was deemed an appropriate comparison.

Male

Figure ten demonstrates the significant difference between the child and adult groups for relative evaporative mass loss in the two hot climates (Appendix C-5). The adult's relative evaporative mass loss was 36% greater than the children's in the hot wet climate and 24% greater in the hot dry climate (Appendix A-4). There were no significant differences between the groups in the neutral climate (Appendix C-5). In comparison to the neutral climate the relative evaporative weight loss significantly increased in the hot wet and hot dry climates (Appendix C-5).

Female

There was a significant difference in the relative evaporative heat loss between the groups in the neutral conditions but not in the two hot conditions (Appendix C-5). There was also a significant increase in the relative evaporative weight loss in the two hotter climates in comparison to the neutral climate (Figure 10).



* significant difference between the adult and the children groups

Figure 10 Relative evaporative weight loss in the neutral and hot climates without radiant heat for the 30 minute exercise test.

EVAPORATIVE HEAT LOSS INDEX

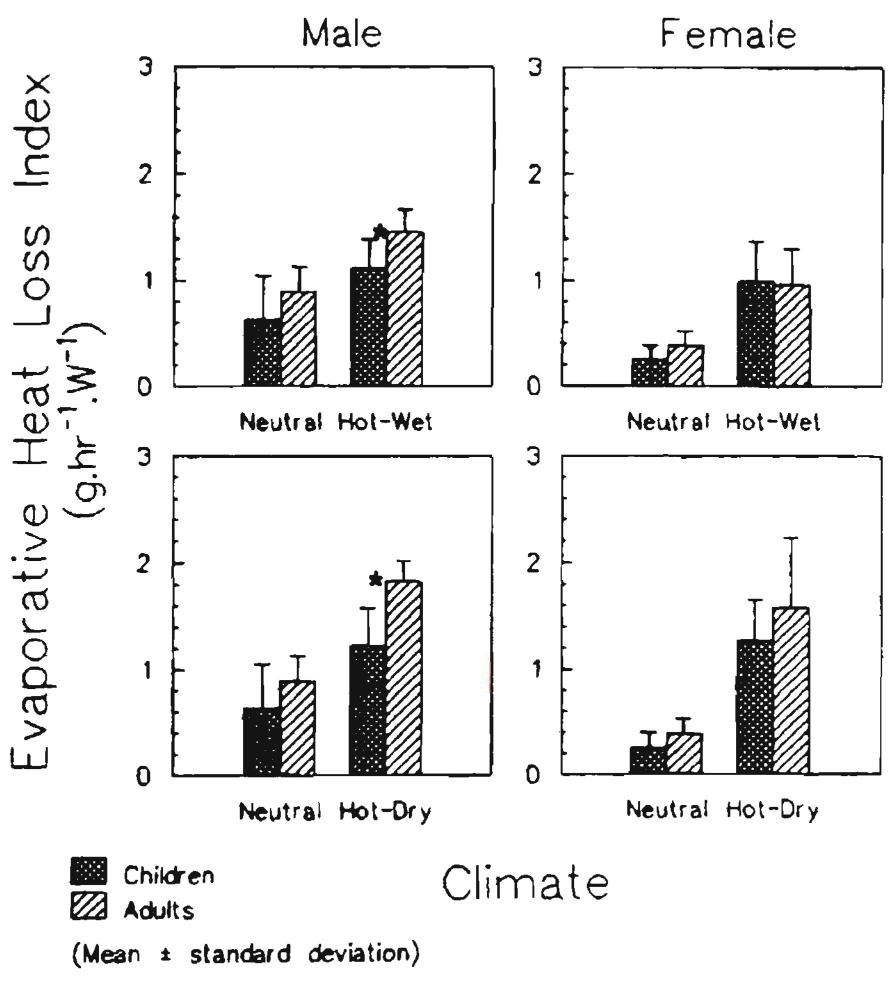
The relative evaporative weight loss does not take into consideration differences in relative heat production between children and adults. To allow for these differences the evaporative heat loss index was calculated (evaporative water loss per unit of heat production).

Male

The children had significantly lower evaporative heat loss indexes than the adults in the two hot climates and a similar evaporative heat loss index (EHLI) in the neutral climate conditions (Appendix C-5). The children's EHLI of 1.13 $gm.hr^{-1}.W^{-1}$ was 29% less than the adult's EHLI of 1.46 $gm.hr^{-1}.W^{-1}$ in the hot wet conditions (Appendix A-5). In the hot dry conditions the children's EHLI of 1.24 $gm.hr^{-1}.W^{-1}$ was 47% less than the adult's EHLI of 1.82 $gm.hr^{-1}.W^{-1}$. There was a significant increase in the evaporative heat loss index between the 22°C, 31°C and 35°C climates, respectively (Figure 11).

Female

There was no significant difference in the evaporative heat loss index between the adults and children (Appendix C-5). There was a significant increase in the evaporative heat loss index between the 22°C, 31°C and 35°C climates, respectively (Figure 11).



* significant difference between the adult and the children groups

Figure 11 Evaporative heat loss index in the neutral and hot climates without radiant heat for the 30 minute exercise test.

5. MEAN BODY TEMPERATURES

MEAN SKIN TEMPERATURE

Total sample

Since the environment was considered to have the major effect on mean skin temperature, males and females were analysed together (Figures 12 and 13). There were no significant effects for mean skin temperature for either status or sex. However there was a significant climate by time interaction where the mean skin temperature decreased in T_a=22°C and increased in the two hotter climates (Appendix C-5). In the 22°C climate the male children decreased by 0.7°C over the 30 minutes of exercise to 27.1°C and the male adults decreased by 1.0°C to 28.3°C over the same time period (Appendix A-8). In the 31°C climate the opposite trend occurred when the male children increased their mean skin temperature by 0.8°C to 34.3°C over the 30 minutes of exercise and the male adults increased by 0.3°C to 34.0°C over the same time period. In the 35°C climate the male children increased their mean skin temperature by 0.6°C to 35.5°C over the thirty minutes of exercise and the male adults increased by 0.5°C to 35.7°C over the same time period. Figure 13 demonstrates a similar pattern for the female subjects. There was also a significant status by sex by climate interaction. The female children had a higher mean skin temperature (+1.2°C) in the 22°C climate than the female adults and the male children had a lower mean skin temperature (-1.2°C) than the male adults in the same environment (Appendix A-8). This difference occurred at 22°C while the mean skin temperatures in the two hotter climates were very similar between the children and the adults. Climate was a significant main effect with the mean skin temperature increasing in relation to the air temperature. In the 22°C environment the mean skin temperature of the females averaged 28.6°C and 27.4°C for the children and adults respectively. In the same environment the mean skin temperature of the male children was 27.3°C and of the male adults was 28.5°C. This indicated that there was a 5 to 6°C skin to air temperature difference in these neutral environmental conditions. In the 31°C environment the mean skin temperature of all the groups averaged between 34.0 & 34.1°C. This was a +3°C skin to air temperature difference in these hot wet environmental conditions. In the 35°C environment the average mean skin temperature of the groups varied between 35.3 & 36.0°C which translated to an air to skin temperature difference of less than 1.0°C.

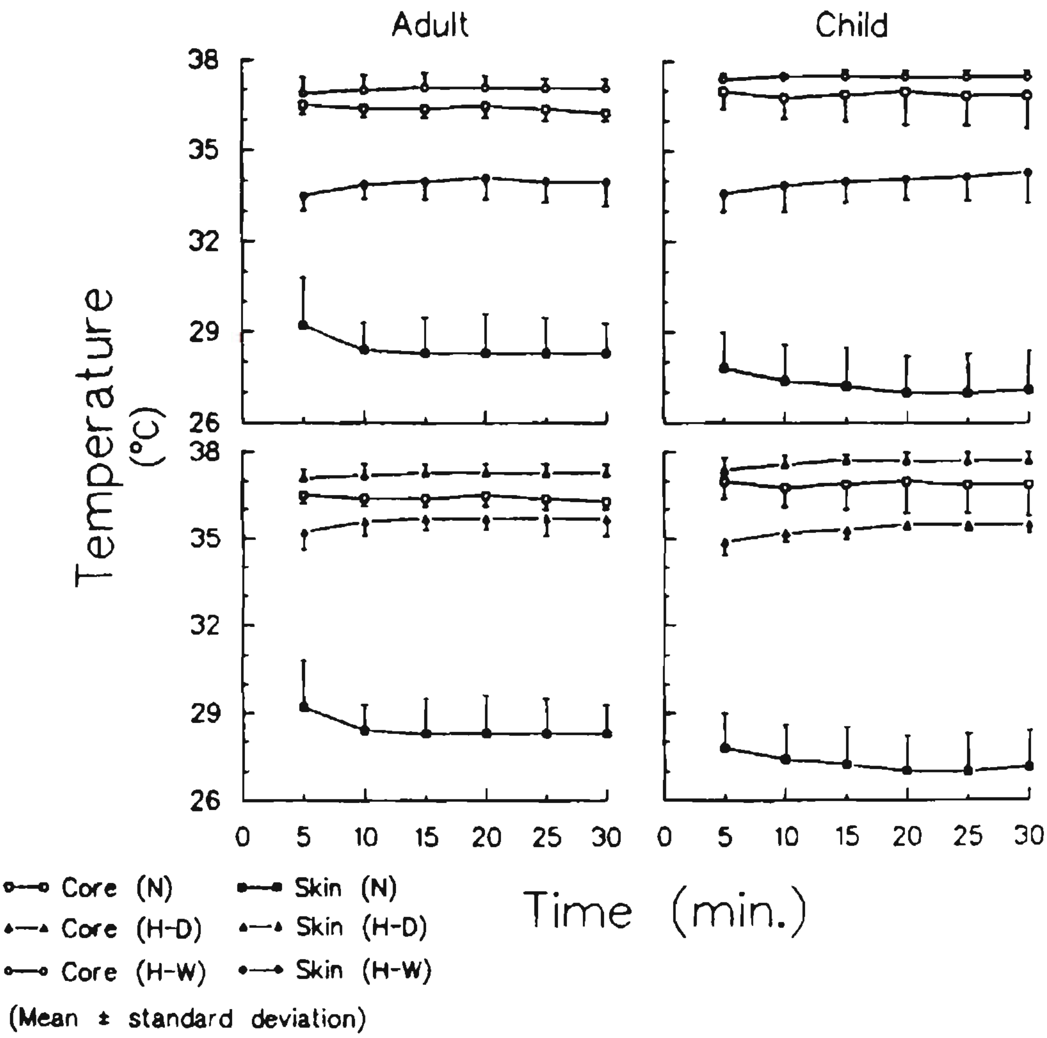


Figure 12 Core and skin temperatures of the male groups in the neutral and hot climates without radiant heat for the 30 minutes of the exercise test.

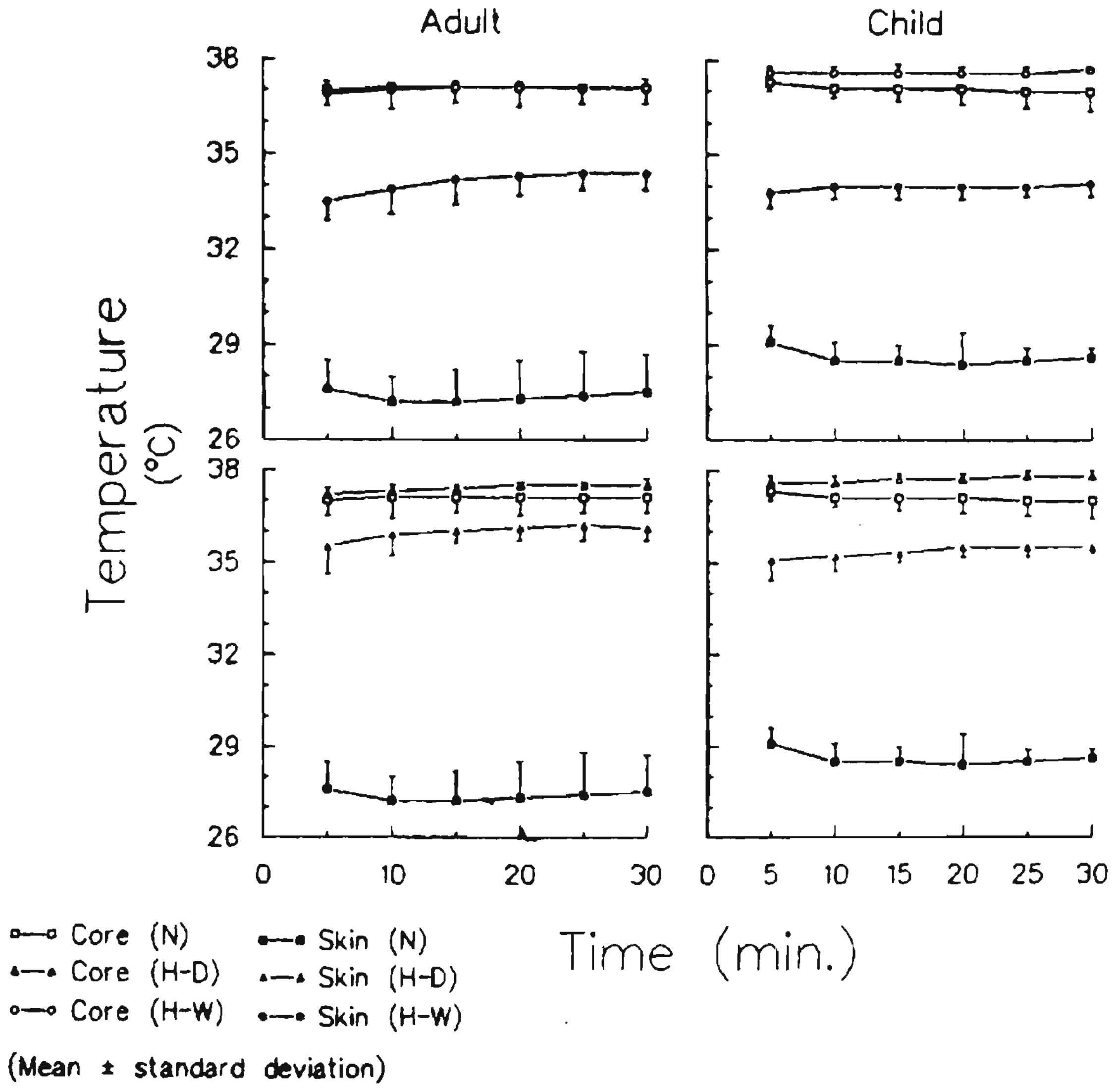


Figure 13 Core and skin temperatures of the female groups in the neutral and hot climates without radiant heat for the 30 minutes of the exercise test.

CORE TEMPERATURE

Total sample

While it might be considered inappropriate to compare male and female groups on core temperature because the female children exercised at a generally lower percentage of VO_2 maximum in the two hot climates it could still be of value to compare them as a six percent lower relative metabolism should have a small effect on core temperature.

There were significant differences on core temperature measured in the ear canal for both status and sex (Figures 12 and 13). The ear canal temperatures of the children's groups were 0.4 to 0.5°C higher than the adults in the two hot climates. In the 22°C climate the male children's core temperature averaged 0.4°C higher than the male adults while the female groups had the same average core temperature (Appendix A-7). The core temperatures of the females were generally higher than the males. In the 22°C climate the females averaged 0.6°C higher than the males. In the 31°C climate the females averaged 0.2°C higher than the males and in the 35°C climate the females averaged 0.1°C higher than the male groups.

There was a significant time by climate interaction with the core temperature increasing in the two hot climates and decreasing in the 22°C climate over the 30 minutes of the exercise test. There was a gradual increase in core temperatures of 0.1 to 0.3°C over the 30 minutes of the exercise test in the two hot conditions and this was similar for both children and adults (Appendices A-7 and C-5). In the 22°C climate there was a gradual drift downwards which averaged 0.1°C across the four groups. There was also a significant climate effect for ear canal temperature. Core temperature was increased in the two hot climates compared to the neutral climate.

6. COVARIATES - SKINFOLDS, SA/MASS, VO_2 MAXIMUM.

Analyses were performed on the dependent variables which had been previously shown to be significantly different between the adult and child groups. The analysis used was a multivariate analysis of covariance technique with repeated measures over time and in the three different climates. The independent variables used as covariates (skinfolds, surface area/mass, VO_2 maximum) were analysed one at a time. Further analyses were undertaken on core temperature to establish the differences between the children and adult groups in the different climates.

COVARIATES EFFECT ON HEART RATE

Male

While surface area/mass was a covariate which eliminated the differences between the adult and child groups for heart rate in each of the three different climates, its regression equation did not reach significance ($p = .066$). Neither skinfolds or VO_2 maximum accounted for the differences in heart rate between the adult and children groups (Appendix C-6).

Females were not considered in this analysis as the child group exercised at a lower percentage of VO_2 maximum than the adult group in the two hot climates.

COVARIATES EFFECT ON PERCENTAGE OF HEART RATE MAXIMUM

Male

While the regression equations for skinfolds and VO_2 maximum were both significantly related to percentage of heart rate maximum neither removed the difference between the adult and child groups. When surface area/mass was covaried with the percentage of heart rate maximum the difference between the children and adult groups was removed but the regression equation did not quite reach significance ($p = .064$) (Appendix C-8).

COVARIATES EFFECT ON HEART RATE INDEX

Total sample

Since there was no difference for the heart rate index between the male and female groups over the three climates it was practical to include all of the subjects together in an analysis of covariance. There were no significant correlations between heart rate index and the three covariates analysed separately. The covariates did not remove the difference between the adult and children groups on the heart rate index (Appendix C-8).

COVARIATES EFFECT ON EVAPORATIVE HEAT LOSS INDEX

Male

Males were considered separately on this variable because the two female groups did not have closely equivalent relative heat productions. The significant difference for the evaporative heat loss index between the two male groups was removed by covarying against the surface area to mass ratio, but its regression equation did not reach significance (Appendix C-6). Neither VO_2 maximum or skinfolds accounted for the difference between the children and adult groups on the evaporative heat loss index.

COVARIATES EFFECT ON CORE TEMPERATURE

Total sample

While neither skinfolds nor VO_2 maximum had significant regression equations with core temperature over the three climates, they both had enough common variance to remove the difference in core temperature between the male and female groups (Appendix C-7). The analysis of covariance was subsequently carried out separately for each climate.

In the neutral climate both VO_2 maximum and skinfolds had enough common variance with core temperature to remove both the sex and status differences. Surface area/mass removed the status difference but not the sex difference. The covariates did not have a significant regression equation with core temperature (Appendix C-7).

In the hot wet climate the three covariates each had enough common variance with core temperature to remove the sex difference but not the status difference. The covariates did not have a significant regression equation with core temperature (Appendix C-7).

In the hot dry climate both skinfolds and VO_2 maximum had enough common variance with core temperature to remove the difference between the male and female groups. Surface area/mass also had enough common variance with core temperature to remove both the sex and status differences between the groups. Surface area/mass had a significant (p = .060) regression equation with core temperature (Appendix C-7). The other two covariates did not have significant regression equations.

PART B: CHILDREN AND ADULTS EXERCISING IN HOT WET CLIMATIC CONDITIONS WITH TWO LEVELS OF RADIANT HEAT.

The purpose of part B of the study was to compare the physiological and thermoregulatory responses of children and adults exercising in a hot wet climate with varying levels of radiant heat and varying levels of metabolism. The first experiment compared the responses of children and adults exercising at 50% VO_2 maximum while being exposed to low and high levels of radiant heat. The second experiment compared the responses of children and adults exercising at increasing levels of metabolism while being exposed to low and high levels of radiant heat. The results of the experiments are presented in sections as follows:

Subjects' characteristics

Experiment one: Constant metabolism with radiant heat

1) Climate chamber conditions
2) Work rate and metabolism
3) Evaporative heat loss responses
4) Mean body temperatures
5) Heart rate responses

Covariate: Surface area/mass ratio

Experiment two: Increasing metabolism with radiant heat

1) Climate chamber conditions
2) Work rates and metabolism
3) Evaporative heat loss responses
4) Mean body temperatures
5) Heart rate responses

Covariate: Surface area/mass ratio

SUBJECTS' CHARACTERISTICS

The average age of the male adults was 23 years and the male children was 10.3 years (Table 35). The adults were approximately twice as heavy as the children and 34cm taller. The average aerobic power of the two groups were similar. The average skinfolds for the children although higher, were not significantly different to the adults. The children's maximum heart rate measured on the cycle ergometer test was significantly greater than the adults. The children's mean maximum heart rate at 200 bts.min^{-1} was 12 beats higher than the mean maximum heart rate of the adults. The ponderal index was not significantly different between the groups. The surface area to mass ratio was significantly different between the groups with the children's group having a 29.5% higher ratio than the adult group.

Table 35 Physical and physiological characteristics of the subjects.

Variables	Adult	Child
Age (yrs)	[1]23.0±4.2[2]	10.3±1.1
Height (cm)	176±5	142±8
Mass (kg)	73.4±8.3	36.3±6.5
VO_2max (ml.kg^{-1}.min^{-1})	51.9±8.4	52.4±5.6
Heart rate max (bts.min^{-1})*	188±3	200±13
Skinfolds (mm)	41.4±11.3	48.2±25.6
Ponderal index	42.1±1.3	43.2±1.4
SA/mass (cm^2.kg^{-1})*	258±13	334±23

* Significant difference between the groups

[1] = mean [2] = standard deviation

EXPERIMENT ONE: CONSTANT METABOLISM TEST IN A HOT WET CLIMATE WITH RADIANT HEAT.

1) CLIMATE CHAMBER CONDITIONS

AIR TEMPERATURE

The chamber was set at T_a=31°C. The air temperature remained close to this level for the first 10 minutes (Figure 14). The radiators were turned on at 10 minutes at either low (T_g = 37°C) or high radiant (T_g=49°C) levels. There was a significant time by radiant heat interaction (Appendix C-9). The radiant heat influx was not fully neutralised by the temperature controller and the air temperature gradually increased to 32°C in the low radiant heat condition and to 34°C in the high radiant heat condition (Figure 14). Similar air temperature conditions were experienced by the adults and the children.

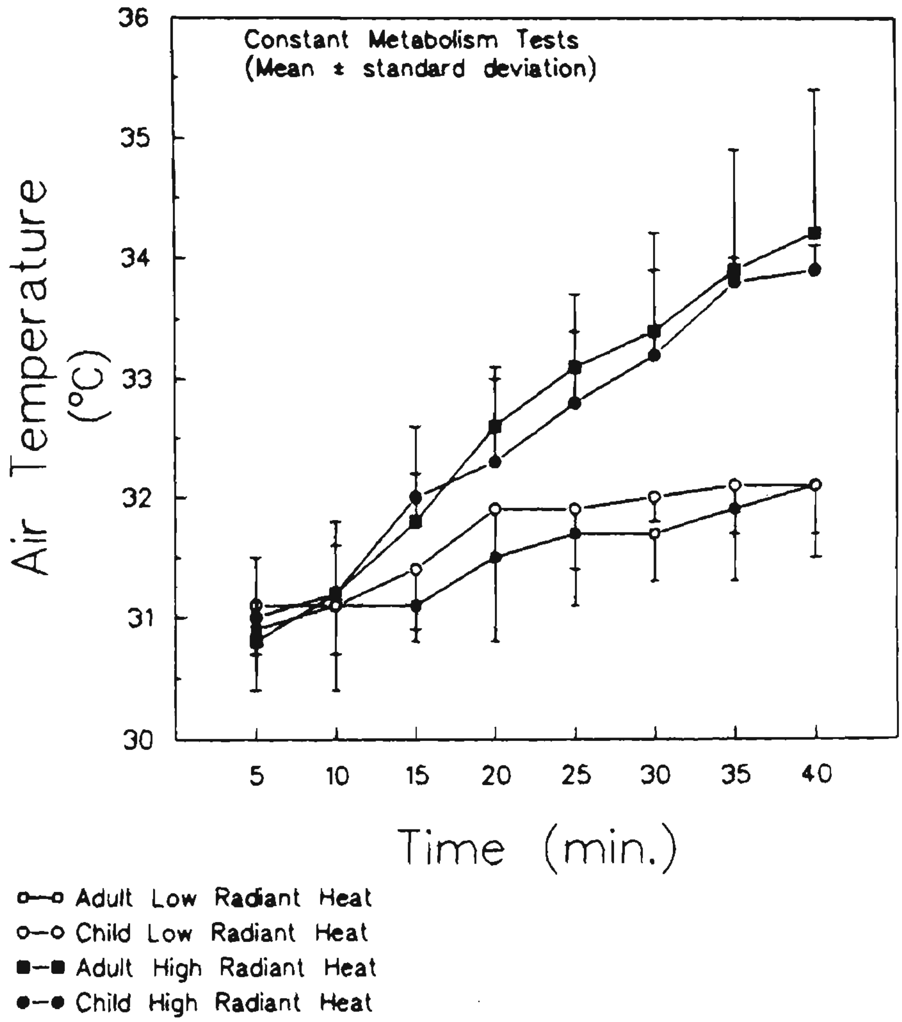


Figure 14 Air temperature in the climate chamber exposed to high and low levels of radiant heat during the constant metabolism test.

RELATIVE HUMIDITY

The chamber was set at a relative humidity of 73% to establish the hot wet conditions experienced in tropical climates. Humidity was harder to control precisely than temperature and was greatly affected by the radiant heaters. The most significant effect was the reduction in humidity over the 40 minutes of the test. In the low radiant heat condition humidity for the whole group was reduced from 80% to 72% (Appendix B-2). In the high radiant heat condition humidity for the whole group was reduced from 77% to 66%. The high radiant heat load reduced the humidity significantly more than the low radiant heat load (Appendix C-9). Another significant factor was the fact that the children's humidity conditions were generally higher than the adults. The mean humidities (average of high and low radiant conditions) for the children's group was 7% higher than the adult group at both the beginning and the end of the 40 minute exercise test (Appendix B-2). It can be claimed that while humidity demonstrated a large variability between groups and over time; it still simulated the hot wet conditions experienced in many tropical climates (Figure 15).

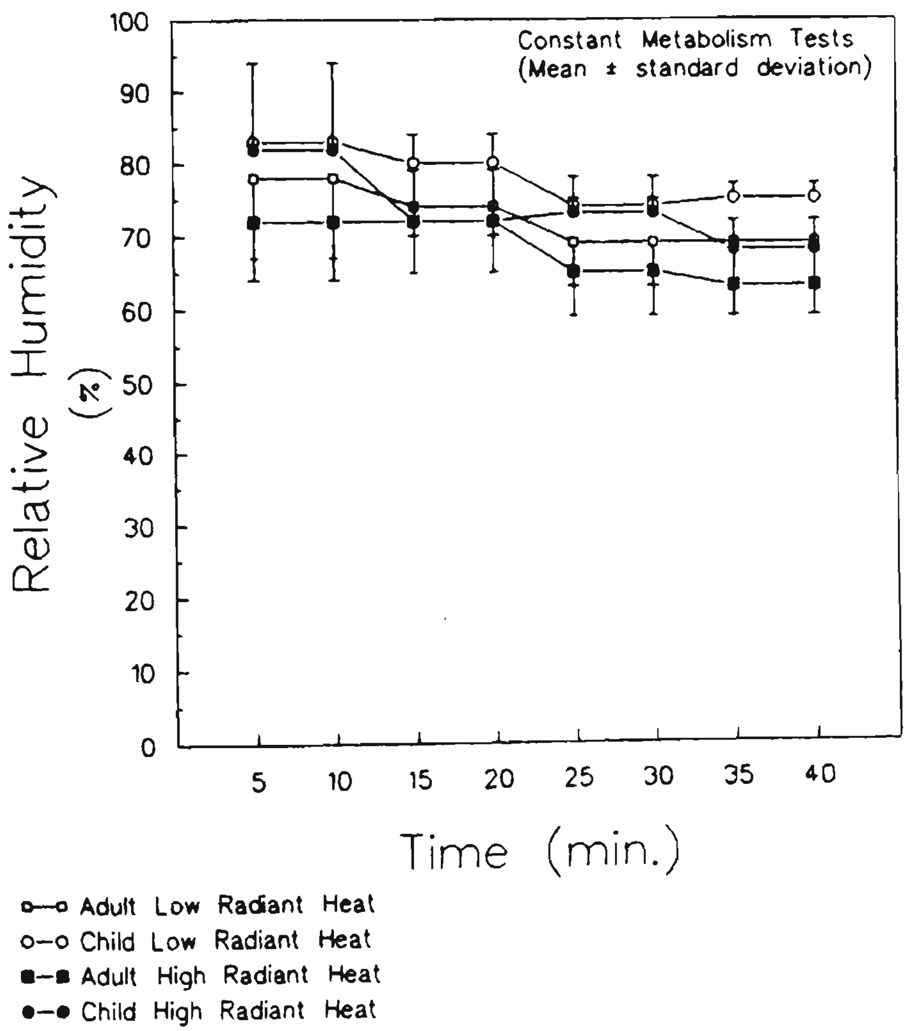


Figure 15 Relative humidity in the climate chamber in radiant heat during the constant metabolism test.

2) WORK RATE AND METABOLISM

WORK RATE

The work rate which elicited 50% VO_2 maximum was approximately three times higher in the adult group than the children's group (Table 36). The children and adults exercised at the same work rate in the low and high radiant heat conditions.

Table 36 Average work rate for the constant metabolism experiment in hot wet conditions with radiant heat.

Group	Work rate (watts)
Adult*	[1]121±21[2]
Child	36±7

* Significant difference between the groups

[1] = mean [2] = standard deviation

OXYGEN UPTAKE

No radiant heat

In the first 10 minutes of the exercise test without radiant heat there were no significant differences in oxygen uptake between the children and adult groups or between the low and high radiant conditions (Appendix C-9). While there were no main effects, there was a group by time interaction. The children reduced their oxygen uptake between 5-10 minutes by an average of 1 $ml.kg^{-1}.min^{-1}$, while the adults increased their oxygen uptake over the same time period by an average of 1 $ml.kg^{-1}.min^{-1}$ (Appendix B-5).

Radiant heat

In the next 30 minutes of the exercise test with the application of either low or high radiant heat loads there were no significant differences for main effects or interactions (Appendix C-9). This indicated that the oxygen uptake remained relatively constant for the duration of the 30 minutes of exercise for both the children and adult groups (Figure 16).

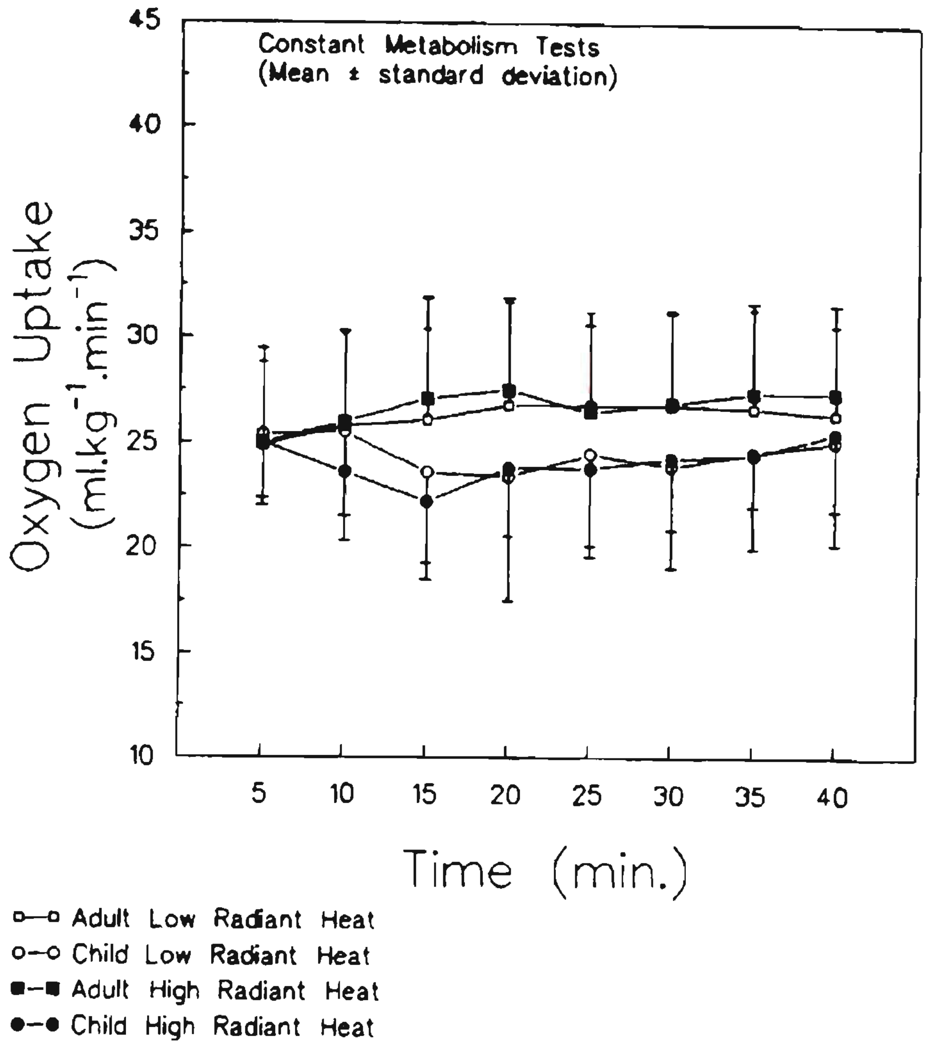


Figure 16 Oxygen uptake for the constant metabolism experiment in hot wet conditions with radiant heat.

MEAN METABOLISM

Since there were no significant main effects in oxygen uptake over either the 10 or 30 minutes of the exercise test it was reasonable to average the data over time and report the results as a mean metabolism. The adult groups mean metabolism was more than twice the score recorded for the children's group (Table 37). There were no significant differences between the low and high radiant conditions (Appendix C-10).

Table 37 Mean metabolism for the constant metabolism experiment in a hot wet climate with radiant heat.

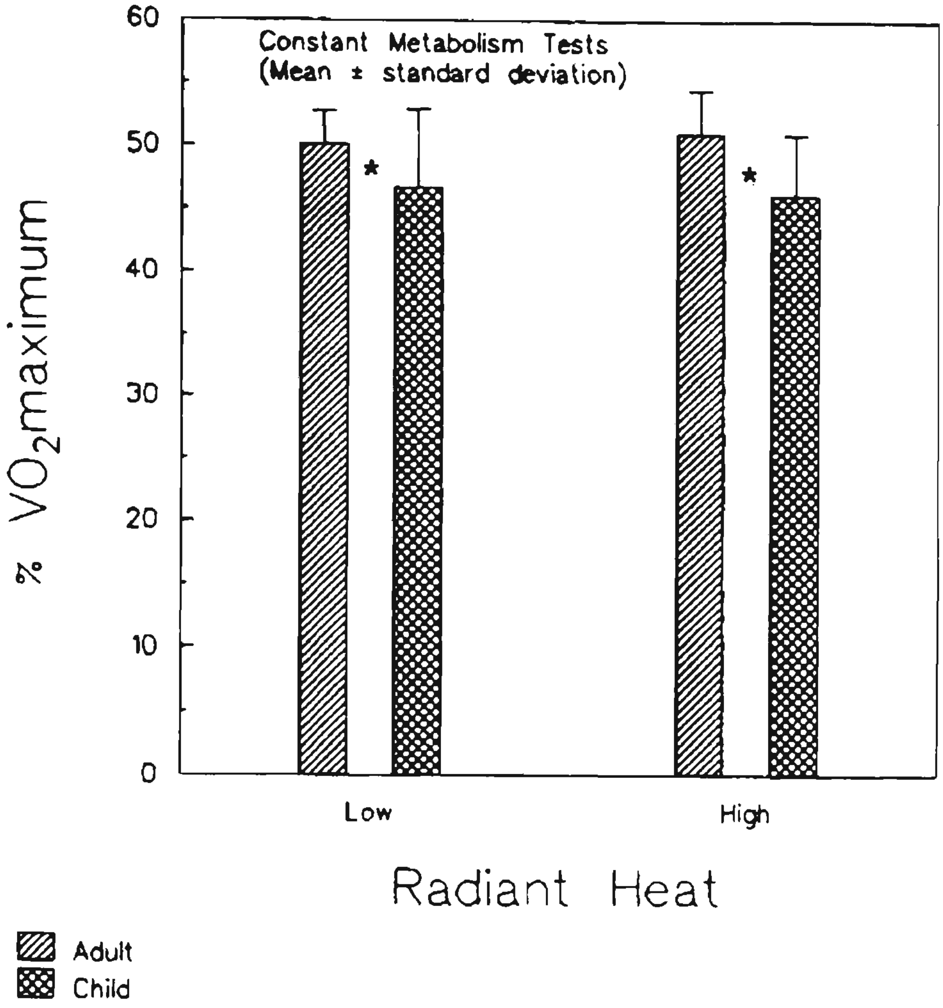
	Mean Metabolism	
	Low Radiant	High Radiant
Group	(Watts)	(Watts)
Adult*	[1]656±88[2]	667±70
Child	297±47	294±41

* Significant difference between the groups

[1] = mean [2] = standard deviation

PERCENTAGE OF MAXIMUM OXYGEN UPTAKE

The children worked at a significantly lower percentage of maximum oxygen uptake than the adults (Appendix C-10). There was no significant difference between the low and high radiant heat conditions. The adults worked at approximately 50% VO_2 maximum and the children worked at approximately 46% VO_2 maximum (Appendix B-3) (Figure 17).

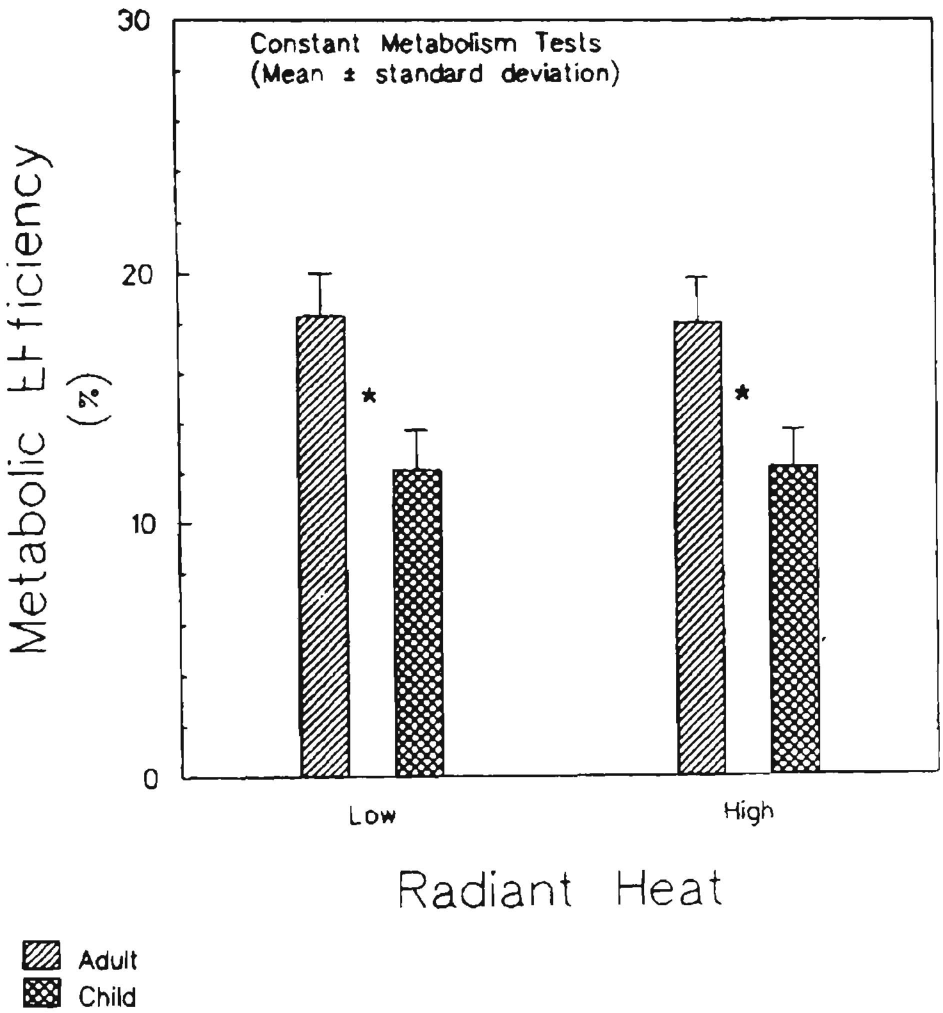


* significant difference between the groups

Figure 17 Percentage of VO_2 maximum for the constant metabolism experiment in a hot wet climate with radiant heat.

METABOLIC EFFICIENCY

Metabolic efficiency was significantly higher for the adults than the children (Appendix C-10). At an exercising level of approximately 50% VO_2 maximum the mean metabolic efficiency for the adult group was 18%, compared to 12% for the children's group (Figure 18). There was no change in metabolic efficiency which resulted from the level of radiant heat.



* significant difference between the groups

Figure 18 Metabolic efficiency for the constant metabolism experiment in a hot wet climate with radiant heat.

HEAT PRODUCTION

The adult group produced significantly more metabolic heat than the children's group (Table 38). When the metabolic heat production was divided by body mass there were no significant differences between the groups (Appendix C-10). Figure 19 illustrates that both groups produced a similar relative metabolic heat stress which was very close to 7.3 $W.kg^{-1}$ (Appendix B-3).

Table 38 Average heat production in the constant metabolism test with radiant heat

	Average Heat Production	
	Low Radiant	High Radiant
Group	(Watts)	(Watts)
Child	[1]261±41[2]	259±36
Adult	535±71	546±54

[1] = mean [2] = standard deviation

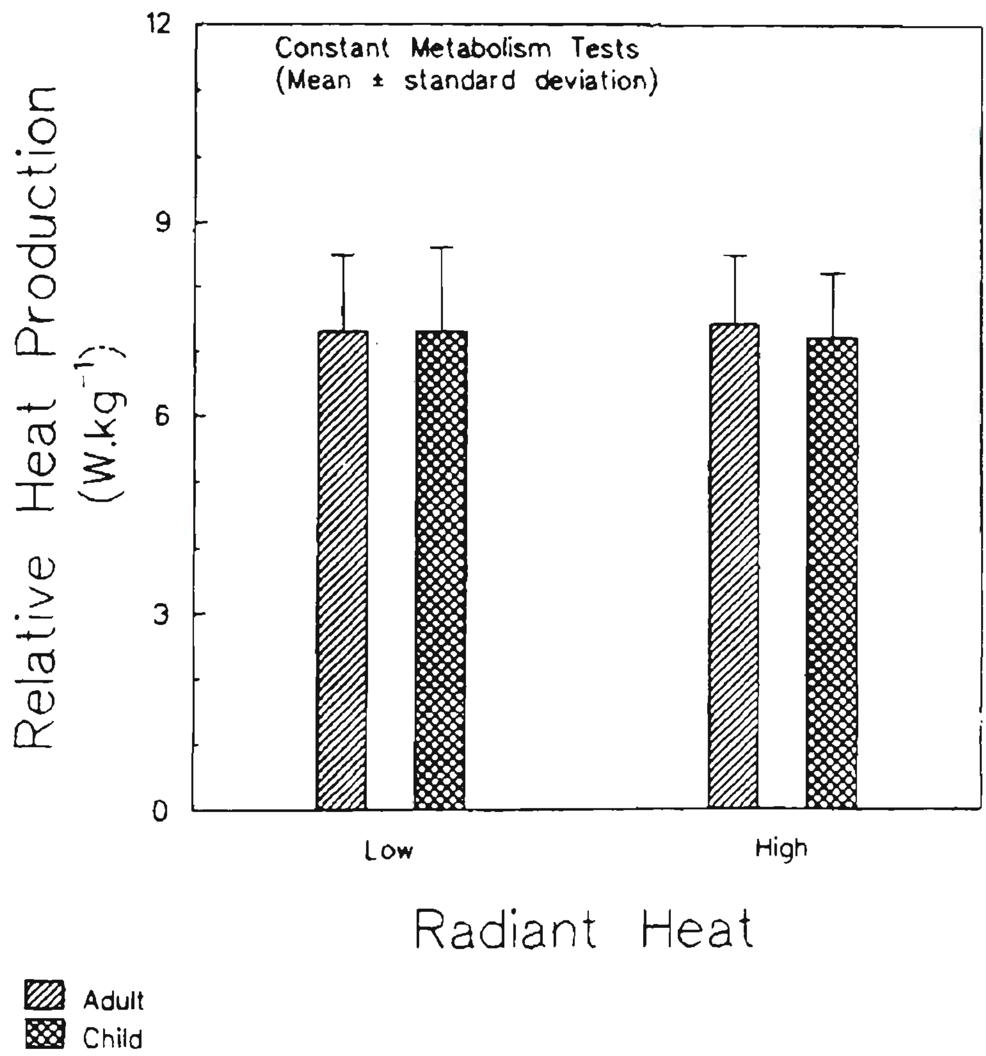


Figure 19 Relative heat prodution for the constant metabolism experiment in a hot wet climate with radiant heat.

3) EVAPORATIVE HEAT LOSS RESPONSES

SWEAT RATE

The adult group sweated significantly more during the 40 minutes of exercise than the children's group (Table 39). Also both groups sweated significantly more when exposed to the high radiant heat load compared to the low radiant heat load (Appendix C-10). The children and adult groups increased their sweat rates by 19.2% and 20.3% respectively in the high radiant condition.

Table 39 Sweat rates for the constant metabolism test in hot wet conditions with radiant heat.

	Sweat Rates	
	Low Radiant	High Radiant
Group	(gm.hr^{-1})	(gm.hr^{-1})
Child*	[1]320±66[2]	381±53
Adult	693±165	834±210

* Significant difference between the groups

[1] = mean   [2] = standard deviation

In order to satisfactorily compare children and adults it was important to make the sweat loss relative to the body mass. There were no significant differences between children and adults for relative sweat rate (Appendix C-10). The children's group sweated at 8.9 gm.kg^{-1}.hr^{-1} and the adult group sweated at 9.4 gm.kg^{-1}.hr^{-1} in the low radiant condition (Appendix B-4). Figure 20 illustrates that both groups also had a similar and significantly higher relative sweat rate in the high radiant condition. The children increased their relative sweat rate by 19.1% to 10.6 gm.kg^{-1}.hr^{-1} and the adults increased by 21.3% to 11.4 gm.kg^{-1}.hr^{-1} (Appendix B-4).

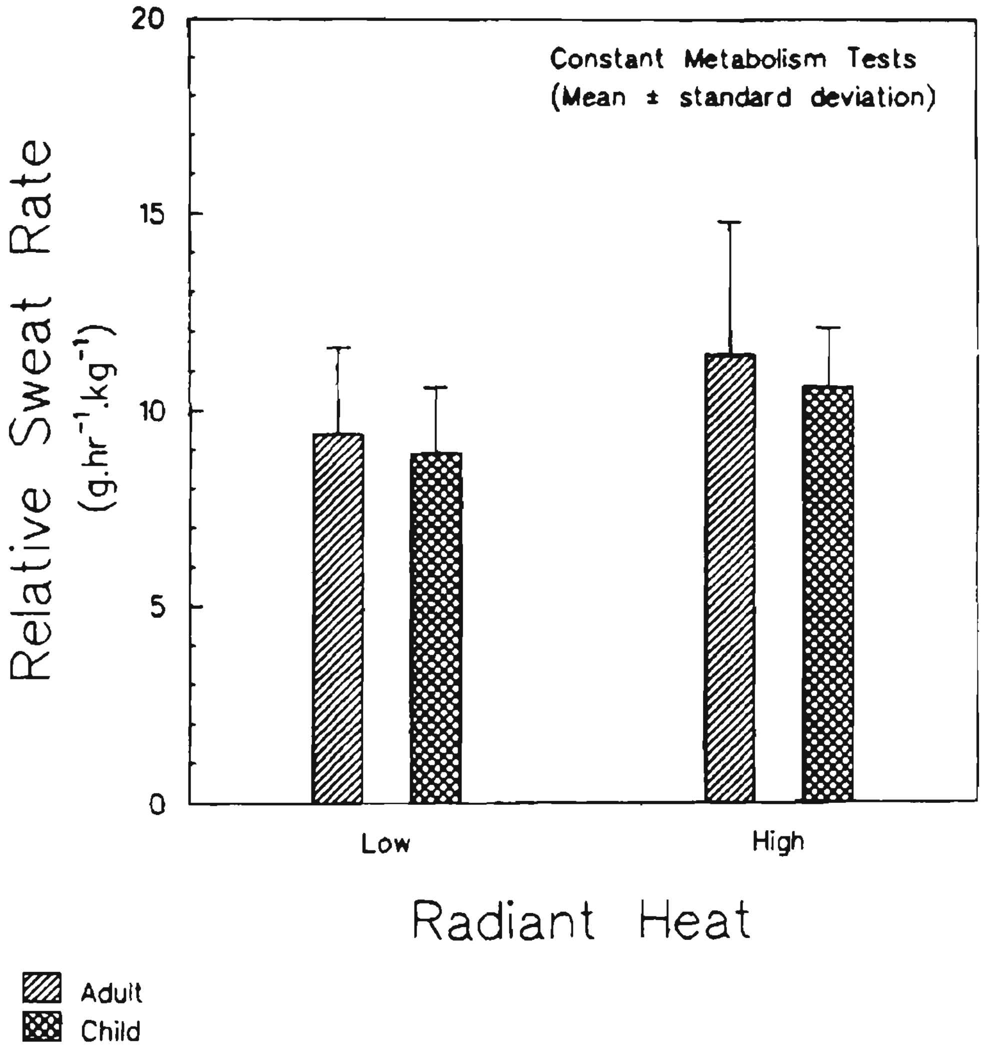


Figure 20 Relative sweat rate for the constant metabolism experiment in a hot wet climate with radiant heat.

SWEAT HEAT LOSS INDEX

The sweat heat loss index (SHLI) is the sweat rate expressed per unit of heat production. This measure standardizes for unequal heat production between individuals and groups. There was no significant difference between the groups for the sweat heat loss index (Appendix C-10). In the low radiant condition the children produced a SHLI of 1.22 $gm.hr^{-1}.W^{-1}$ and the adults produced a SHLI of 1.30 $gm.hr^{-1}.W^{-1}$ (Appendix B-4). Both groups produced a similar and significantly higher sweat heat loss index exercising in the high radiant heat condition compared to the low radiant heat condition. The children's SHLI was 21.3% higher in the high radiant condition compared to the low radiant condition and similarly the adults was 18.5% higher.

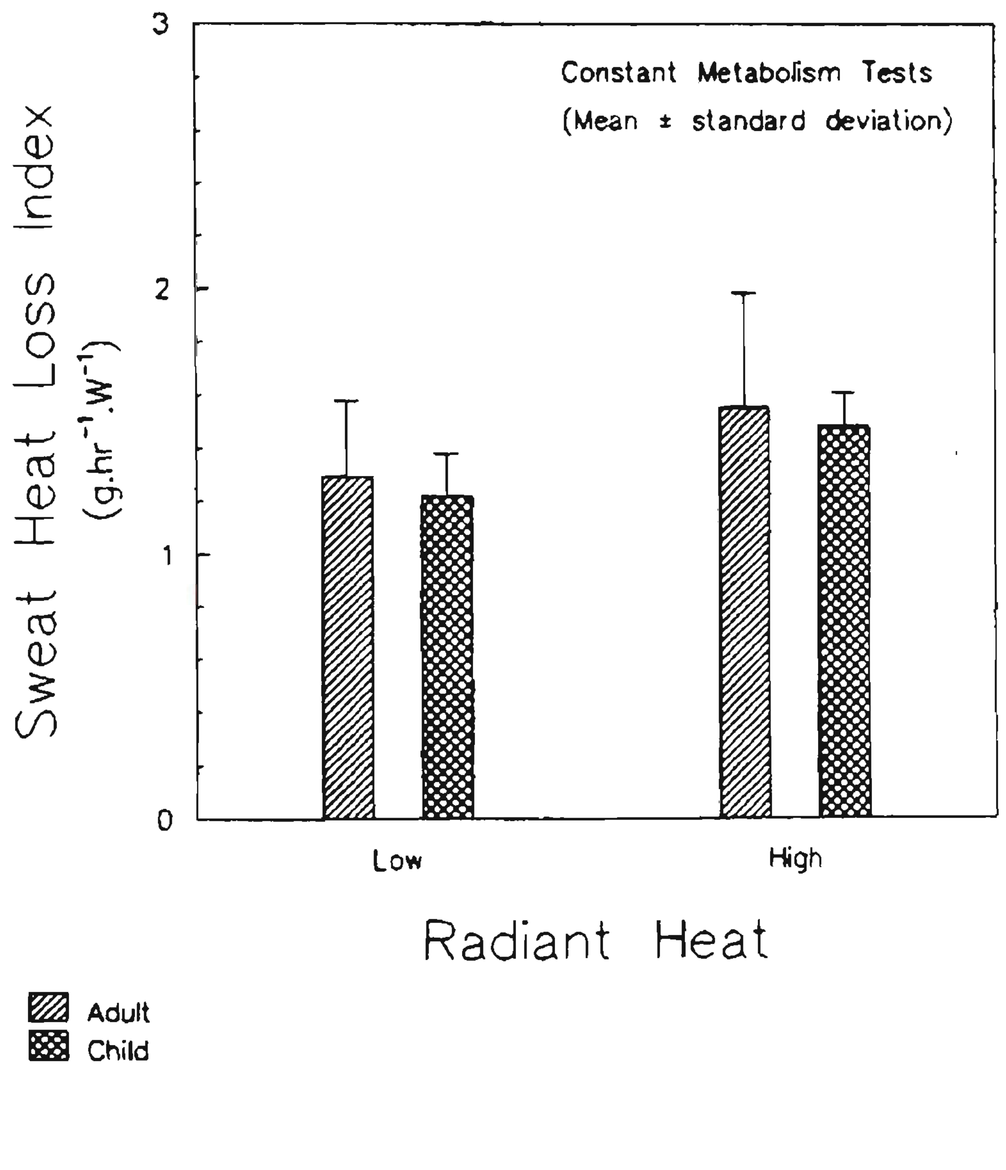


Figure 21 Sweat heat loss index for the constant metabolism experiment in a hot wet climate with radiant heat.

4) MEAN BODY TEMPERATURES

CORE TEMPERATURE

No radiant heat

In the first 10 minutes of the exercise test without radiant heat there was a significant difference in core temperature between the child and adult groups (Appendix C-11). The children started exercising with a T_{ec} which was 0.3°C higher than the adults in both the high and low radiant conditions (Appendix B-11). There was also a significant time effect with the core temperature rising 0.1°C between 5 and 10 minutes of exercise (Figure 22). This result was considered to be inconsequential because the change in the core temperature was equal to the maximum precision of the temperature measuring device.

Radiant heat

During the following 30 minutes of exercise there was a significant difference in T_{ec} between the children and adult groups (Appendix C-11). The children were 0.3°C higher than the adults at 15 minutes and 0.2°C higher at 40 minutes of the exercise test (Appendix B-11). There was also a small but significant increase in the core temperature over time. Since this increase was approximately 0.1°C and the precision of the thermistor probe was also 0.1°C this effect was disregarded. There was also a trend for the core temperature to increase by 0.1-0.2°C in the high radiant condition compared to remaining stable in the low radiant condition (Figure 22).

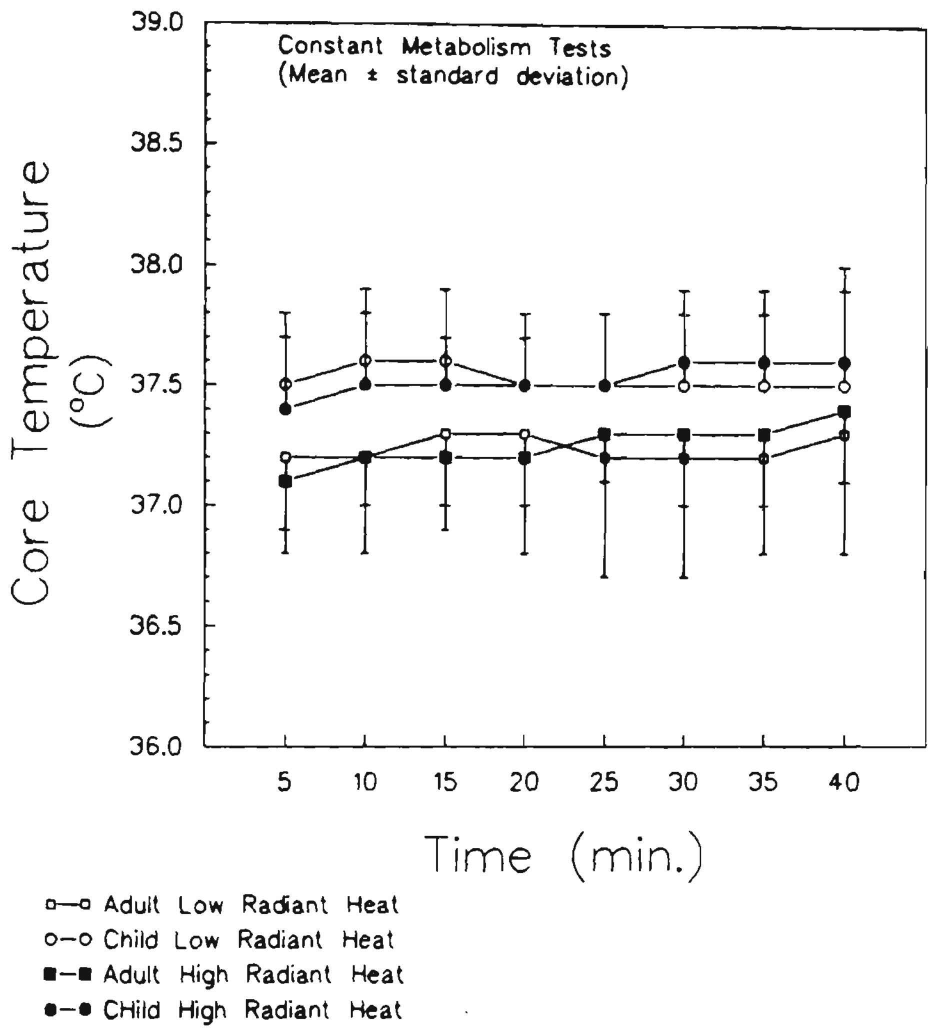


Figure 22 Core temperature for the constant metabolism experiment in a hot wet climate with radiant heat.

SKIN TEMPERATURE - NOT EXPOSED TO RADIANT HEAT (T_{snr})

No radiant heat

In the first 10 minutes of exercise without radiant heat there was a significant difference in skin temperature between the children and adult groups (Appendix C-11). At 5 minutes the children's average T_{snr} = 33.8°C and the adults average T_{snr} = 33.0°C (Appendix B-9). The average difference between the groups was considered to be a real one as the 0.8°C difference was larger than the 0.5°C precision of the infrared gun which was used to measure these temperatures. Both groups skin temperatures significantly decreased over the next 5 minutes. The 0.2°C average decrease of the adult group and the 0.1°C average decrease by the children's group could be a statistical artifact as these changes are smaller than the precision of the measurements (Figure 23).

Radiant heat

In the 30 minutes of exercise with the application of a radiant heat load to other regions of the body there was a significant difference between the child and adult groups (Appendix C-11). At 15 minutes the average T_{snr} of the adult group was 33.1°C and the average T_{snr} of the children's group was 34.0°C (Appendix B-9). This difference of 0.9°C between the groups was larger than the 0.5°C precision of the measuring device and appears to be a real difference. Also over the 30 minutes of exercise there was a significant difference in T_{snr} between the low and high radiant conditions. This difference was interpreted as a trend as it was no greater than the precision of the measuring instrument. The significant increase in T_{snr} over time was also interpreted as a trend as the increase was less than the precision of the instrument. The significant interaction where the adult group increased on T_{snr} more over time in the high radiant heat than the children's group was also considered a trend for the same reason described above (Figure 23).

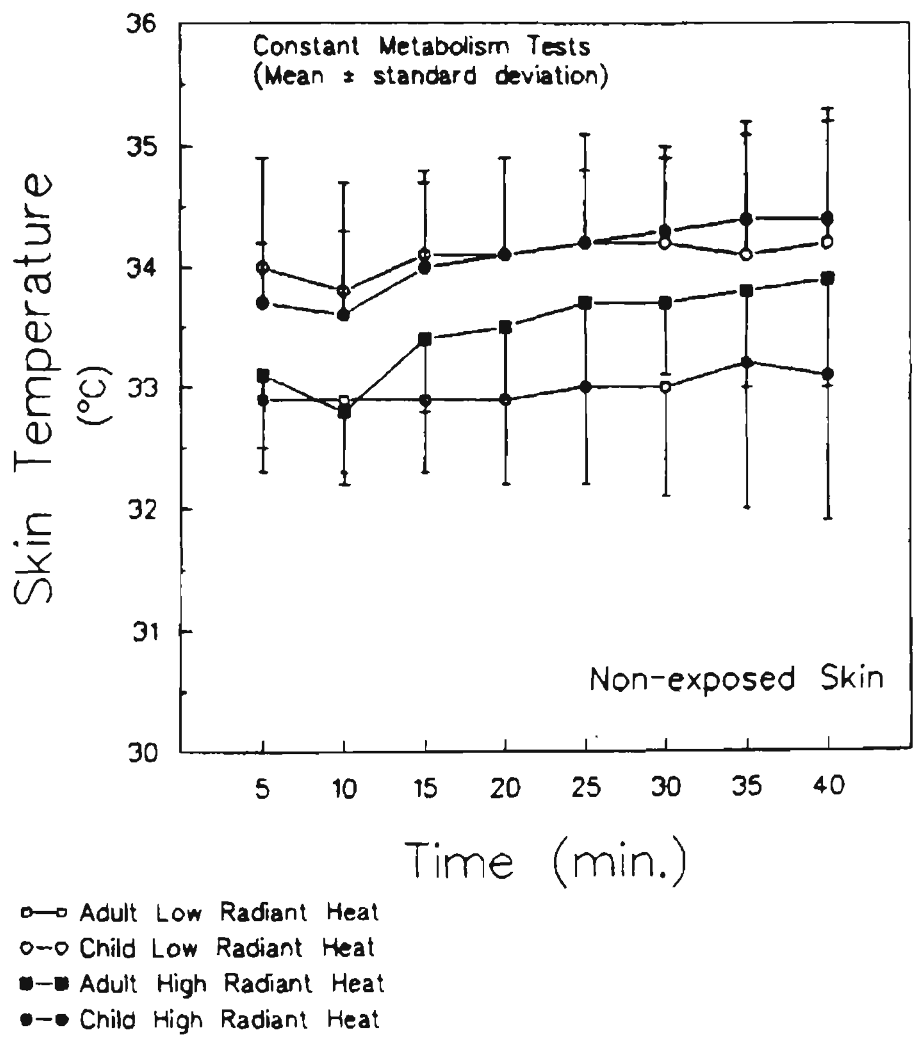


Figure 23 Skin temperature not exposed to radiant heat for the constant metabolism experiment in a hot wet climate with radiant heat.

SKIN TEMPERATURE - EXPOSED TO RADIANT HEAT (T_{ser})

No radiant heat

There was a significant difference in mean skin temperature between the adult and child groups (Appendix C-12). The children averaged 1.7°C higher than the adults at both 5 and 10 minutes of exercise (Appendix B-10). There was no significant difference for the level of radiant heat. Both the time effect where there was a 0.3°C decrease in T_{ser} and the radiant by time effect where there was a 0.5°C greater decrease in T_{ser} in the high radiant condition compared to the low radiant condition were considered to be trends as these differences were similar or less than the precision of the measuring instrument (Appendix B-10).

Radiant heat

There was a significant difference in T_{ser} between the child and adult groups for both levels of radiant heat (Appendix C-12). The children's T_{ser} averaged 1.1-2.0°C above that of the adults in both the low and high radiant heat conditions (Appendix B-10). There was a significant difference in T_{ser} between the high and low radiant heat conditions. Both groups averaged approximately 3.0°C higher in the high radiant heat condition. The other effects were not considered to be significant because the differences were less or similar to the precision of the measuring instrument (Figure 24). Therefore the 0.5°C average increase in T_{ser} over time, the 0.3°C greater increase in T_{ser} in the high radiant condition compared to the low radiant condition over time and the 0.4°C greater increase in T_{ser} for the adults in comparison to the children over time were all considered to be trends (Appendix B-10).

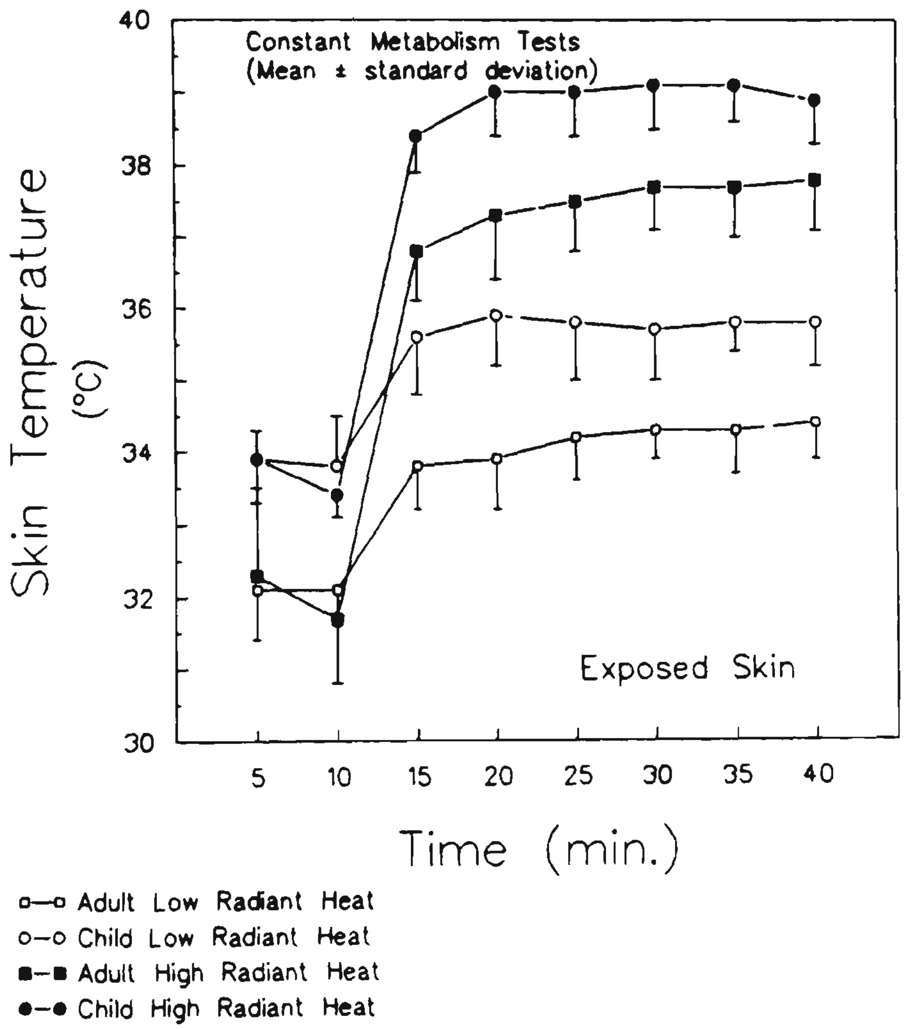


Figure 24 Skin temperature exposed to radiant heat for the constant metabolism experiment in a hot wet climate with radiant heat.

5) HEART RATE RESPONSES

HEART RATE

No radiant heat

In the first 10 minutes of exercise without exposure to radiant heat there was a significant difference in heart rates between the two groups (Appendix C-12). At 5 minutes of exercise the adult group averaged 111 bts. min^{-1} and the children's group averaged 135 bts.min^{-1} (Appendix B-6). There was a significant difference between the high and low radiant heat conditions. At 5 minutes of exercise the childrens group was 7 bts.min^{-1} lower and the adult group was 2 bts.min^{-1} lower in the high radiant compared to the low radiant heat condition. There was also a significant time effect with a gradual cardiovascular drift between 5 and 10 minutes of exercise. The children's group increased by an average of 4 bts.min^{-1} and the adult group increased by an average of 5 bts.min^{-1} (Figure 25).

Radiant heat

In the 30 minutes of exercise where the radiant heat was exposed to the skin's surface there was a significant difference between the two groups (Appendix C-12). At 15 minutes the adult group averaged 120 bts. min^{-1} and the children's group averaged 138 bts.min^{-1} (Appendix B-6). There was a significant cardiovascular drift for both groups over time with a higher cardiovascular drift in the high radiant heat condition. The average cardiovascular drift in the high radiant condition was 16 beats compared to 7 beats in the low radiant condition (Figure 25).

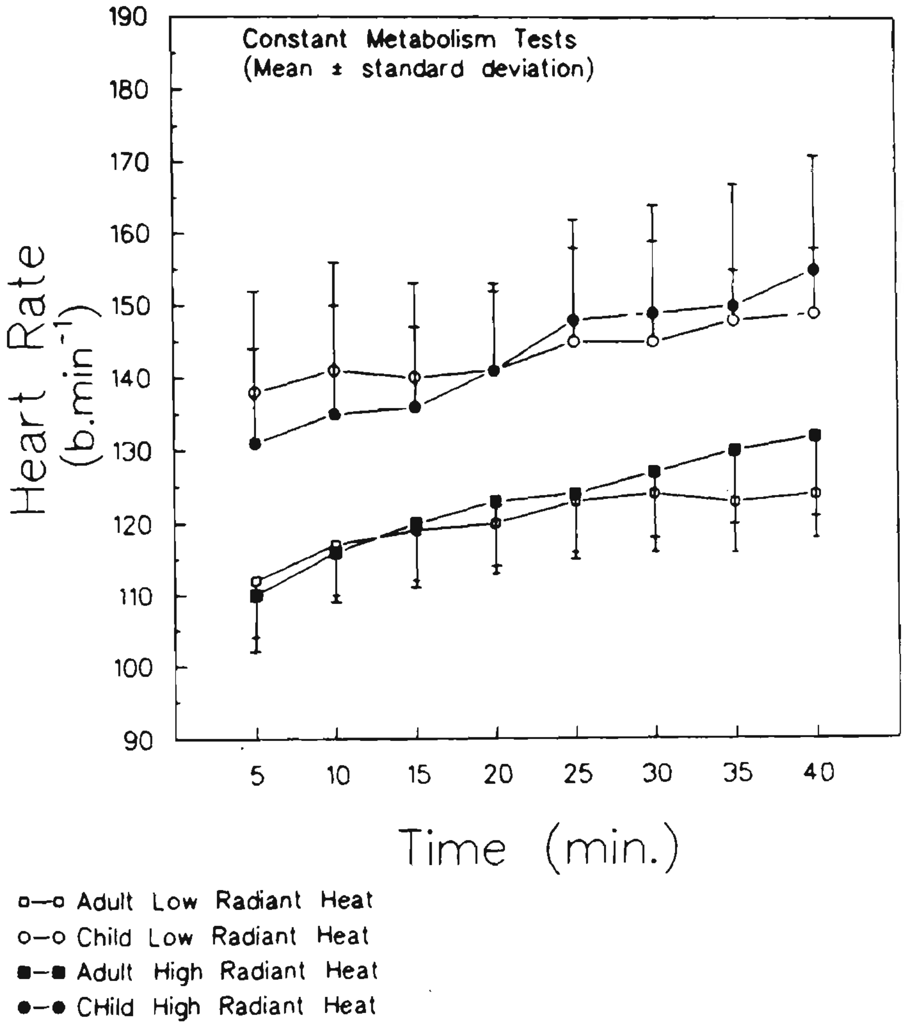


Figure 25 Heart rate for the constant metabolism experiment in a hot wet climate with radiant heat.

PERCENTAGE OF MAXIMUM HEART RATE

The 30 minutes of exercise with a radiant heat load demonstrated a significant difference between the groups (Appendix C-13). At 15 minutes the children's group exercised at 69% of heart rate maximum and the adult group exercised at 63% of heart rate maximum (Appendix B-7). There was a significant increase in the percentage of maximum heart rate over time. At 40 minutes the children's group averaged 76% of heart rate maximum and the adult group averaged 69% of heart rate maximum. The children's cardiovascular drift averaged 7% and the adults averaged 6%. The cardiovascular drift was significantly greater in the high radiant heat condition than the low radiant heat condition. The children's percentage of heart rate maximum in the high radiant condition drifted by 9% compared to 5% in the low radiant condition. The adult's percentage of heart rate maximum in the high radiant heat condition drifted by 7% compared to 3% in the low radiant heat condition (Figure 26).

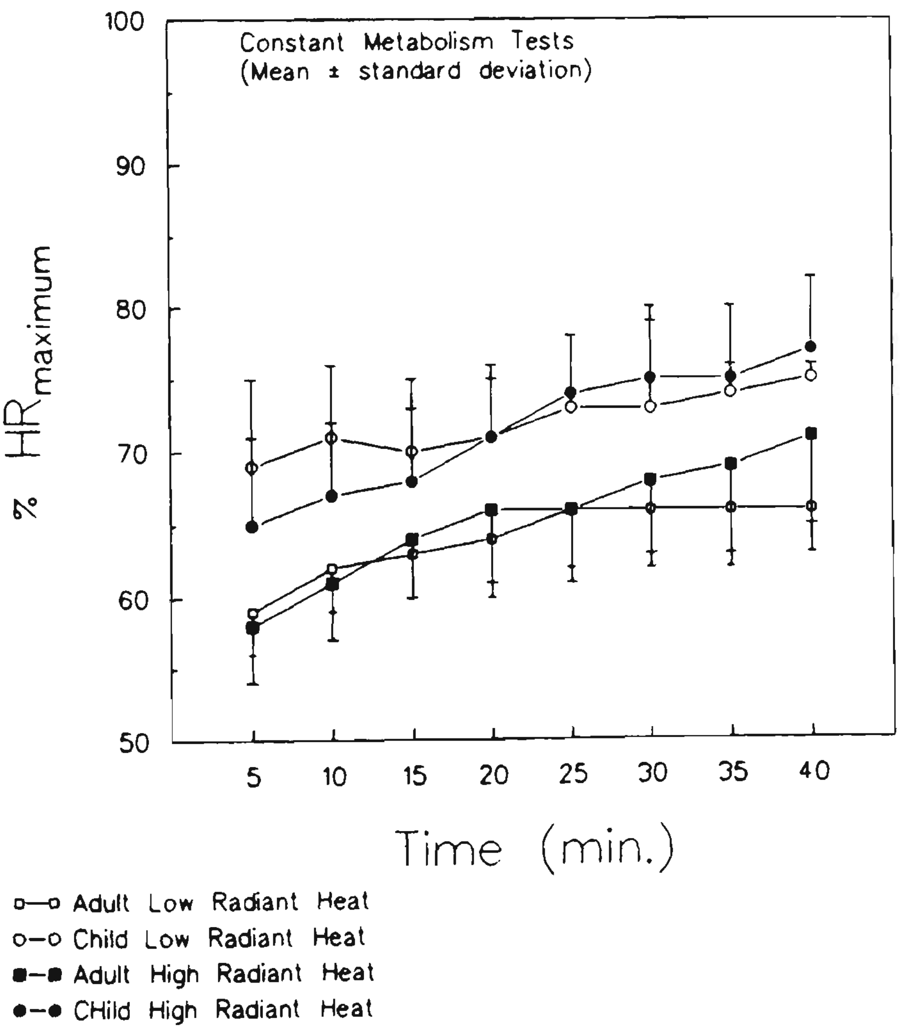


Figure 26 Percentage of heart rate maximum for the constant metabolism experiment in a hot wet climate with radiant heat.

HEART RATE INDEX

The heart rate index (HRI) was determined to standardize for the effect of the two groups exercising at different percentages of VO_2 maximum. The children's group had a significantly higher heart rate index than the adult group (Appendix C-13). The children's HRI averaged 1.57 over the 40 minutes of the exercise test and the adult's HRI averaged 1.28 over the same time period (Appendix B-8). Figure 27 illustrates that the children's group drifted significantly more on the heart rate index over the 40 minutes of the exercise test than the adult group. The children's drift on the HRI averaged over both radiant conditions was .16 compared to the adults .09 drift in the same conditions (Appendix B-8).

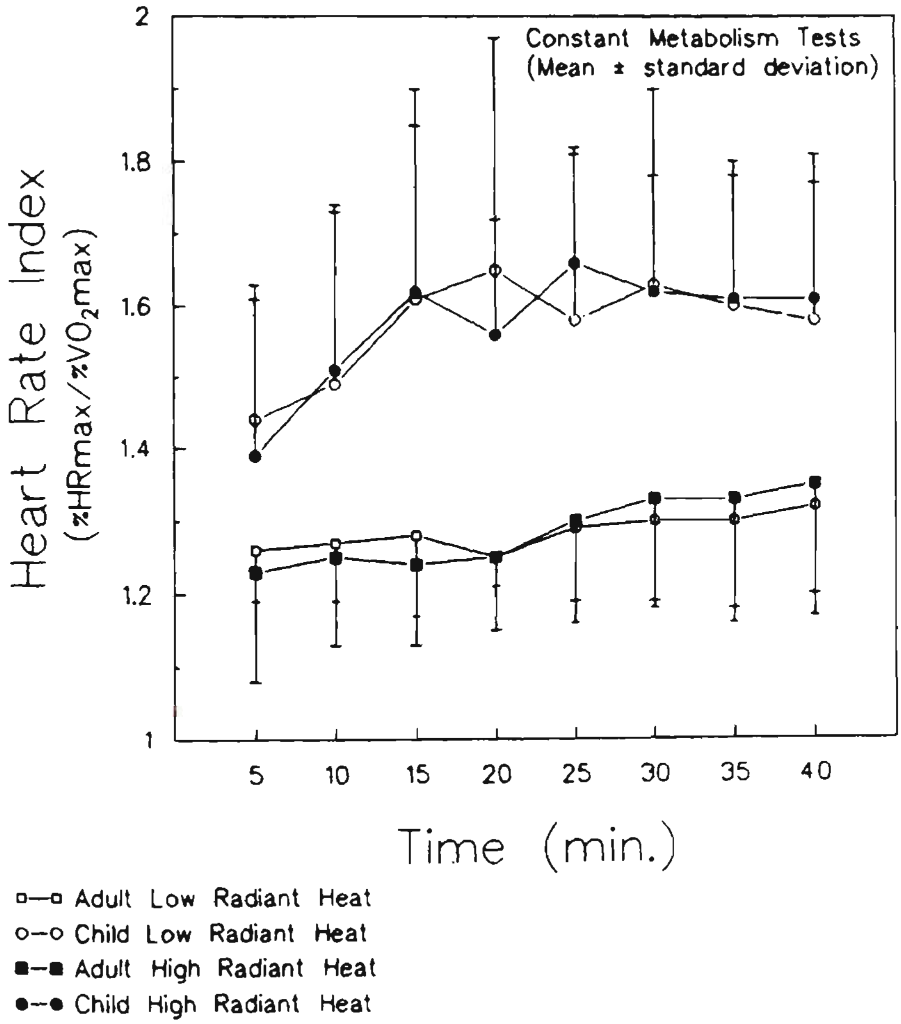


Figure 27 Heart rate index for the constant metabolism experiment in a hot wet climate with radiant heat.

COVARIATE - SURFACE AREA/MASS

The analyses of covariance were performed separately on the dependent variables measured:

(1) in the first 10 minutes and

(2) the last 30 minutes of the constant metabolism exercise test.

The dependent variables which were analysed had already been shown to be significantly different between the adult and children groups. Surface area/mass was chosen as the covariate because it was the only independent variable which is linked to temperature regulation and was also found to be significantly different between the adult and children groups.

CORE TEMPERATURE AND SURFACE AREA/MASS

10 minutes:

Surface area/mass was not significantly correlated with core temperature but the common variance between them removed the significant difference between the child and adult groups at the p = .050 level (Appendix C-18).

30 minutes:

Surface area/mass was not significantly correlated with core temperature but the common variance between them removed the significant difference between the adult and child groups (Appendix C-18).

SKIN TEMPERATURE (T_{ser}) AND SURFACE AREA/MASS

10 minutes:

Surface area/mass was significantly correlated with skin temperature which was not exposed to radiant heat and the common variance between these variables removed the significant difference between the child and adult groups (Appendix C-18).

30 minutes:

Surface area/mass was not correlated with T_{ser} when it was exposed to radiant heat and the common variance between them did not remove the difference between the child and adult groups (Appendix C-18).

SKIN TEMPERATURE (T_{snr}) AND SURFACE AREA/MASS

10 minutes:

Surface area/mass was not significantly correlated with skin temperature (T_{snr}) but the common variance between these variables removed the significant difference between the adult and child groups (Appendix C-18).

30 minutes:

Surface area/mass was not significantly correlated with skin temperature (T_{snr}) but the common variance between them removed the significant difference between the adult and child groups (Appendix C-18).

PERCENTAGE OF HEART RATE MAXIMUM AND SURFACE AREA/MASS

10 minutes:

Surface area/mass was not significantly correlated to the percentage of heart rate maximum but the common variance between them removed the significant difference between the child and adult groups (Appendix C-18).

30 minutes:

Surface area/mass was not significantly correlated to the percentage of heart rate maximum but the common variance between them removed the significant difference between the adult and child groups (Appendix C-18).

EXPERIMENT TWO: INCREASING METABOLISM TEST IN A HOT WET CLIMATE WITH RADIANT HEAT.

1) CLIMATE CHAMBER CONDITIONS

AIR TEMPERATURE

During the 30 minutes of the exercise test there was a significant time by level of radiant heat interaction (Appendix C-14). The chamber was set at T_a = 31°C at the beginning of the test and increased to approximately 32°C in the low radiant heat condition and approximately 33.5°C in the high radiant heat condition (Figure 28). There were no significant differences between the child and adult groups.

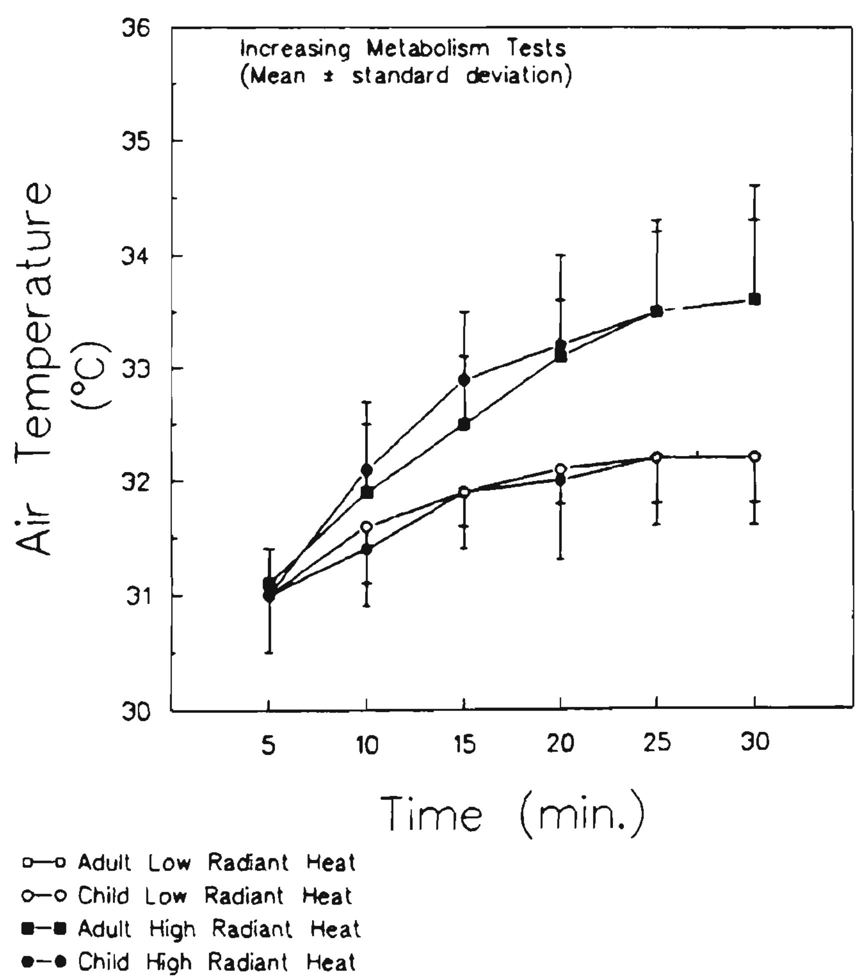


Figure 28 Air temperature in the climate chamber for the increasing metabolism experiment in a hot wet climate with radiant heat.

RELATIVE HUMIDITY

The chamber was set at a relative humidity of 73% to establish the hot wet conditions experienced in tropical climates. Humidity was harder to control precisely than temperature and was greatly affected by the radiant heaters (Figure 29). During the 30 minutes of the exercise test there was a significant decline in relative humidity (Appendix C-14). The relative humidity for the children's group decreased from 90% to 74% in the low radiant condition and from 75% to 71% in the high radiant condition. The relative humidity for the adult group decreased from 74% to 70% in the low radiant condition and from 67% to 65% in the high radiant heat condition. The relative humidity of the children's group was significantly higher than the relative humidity of the adult group. This difference between the groups averaged 12% in the first 10 minutes and 6% for the last 20 minutes of the exercise test. It can be claimed that while humidity in the climate chamber demonstrated a large variability between the groups and over time, it still simulated the hot wet conditions experienced in many tropical climates (Figure 29).

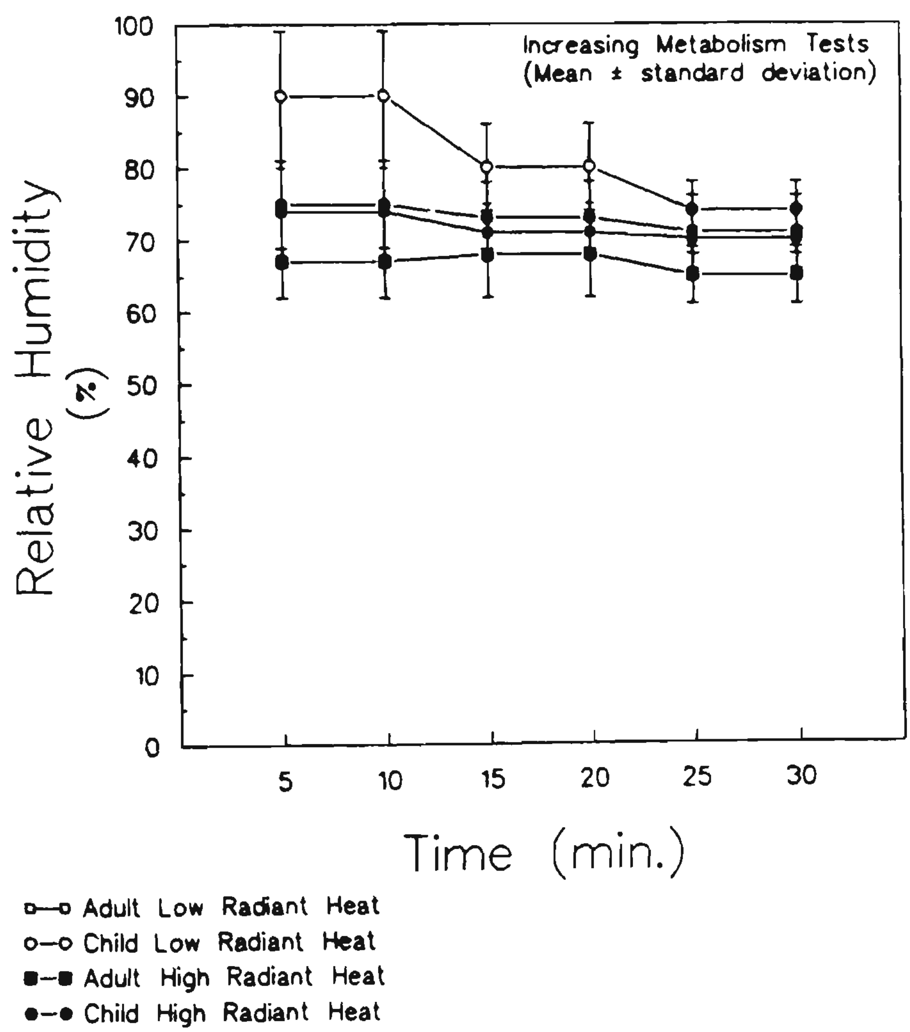


Figure 29 Relative humidity in the climate chamber for the increasing metabolism experiment in a hot wet climate with radiant heat.

2) WORK RATES AND METABOLISM

WORK RATES

The increasing metabolism exercise test was designed to have three 10 minute workloads at easy, moderate and hard intensities. There was a significant interaction between group and work level (Appendix C-14). The adult group work rates increased by approximately 40 watts at each progressive level of the exercise test and the children increased by approximately 15 watts between each level. The work rates in the high and low radiant heat were equal (Table 40).

Table 40 Work rates for the increasing metabolism test in hot wet conditions with radiant heat

Group	Easy Workload (watts)	Moderate Workload (watts)	Hard Workload (watts)
Adult*	[1]82±19[2]	118±24	160±27
Child	23±8	38±8	52±8

* Significant difference between the groups

[1] = mean [2] = standard deviation

OXYGEN UPTAKE

Figure 30 illustrates a significant interaction in oxygen uptake between the groups and the two levels of radiant heat (Appendix C-14). The average VO_2 of the childs group in the low radiant heat at 24.3 ml. kg^{-1}.min^{-1} was 8% lower than the average VO_2 of the adult group in the same conditions at 26.2 ml. kg^{-1}.min^{-1}. There was a minimal difference between the children and adult groups exercising in the high radiant heat condition with the average VO_2's recorded at 26.7 and 26.9 ml.kg^{-1}.min^{-1} respectively (Appendix B-15).

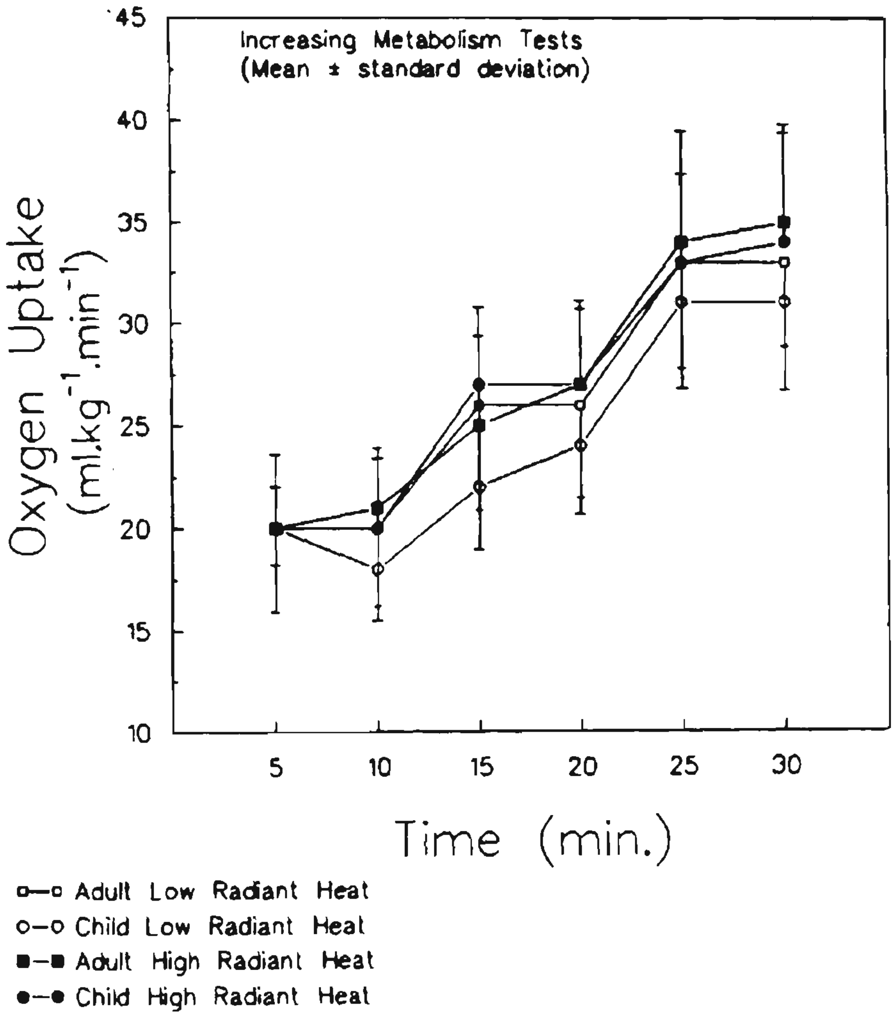


Figure 30 Oxygen uptake for the 30 minutes of the increasing metabolism experiment in a hot wet climate with radiant heat.

AVERAGE METABOLISM

Since the oxygen uptake appeared to change minimally within each 10 minute workload (no more than 2 $ml.kg^{-1}.min^{-1}$) it was considered appropriate to average the two oxygen uptakes at each level in each test and report average metabolism results. The average metabolism was significantly different between the two groups (Appendix C-15). The average metabolism of the adult group was approximately double the average metabolism of the children's group at each work rate level. There was also a signficant difference for the group by level interaction. The adult group's average metabolism increased more over the three levels of metabolism than the children's group (Figure 31). The average metabolism was significantly different in the two radiant heat conditions. The average metabolism for the high radiant heat condition was 4-6% higher over the three different work rates than the average metabolism for the low radiant heat condition (Appendix B-13).

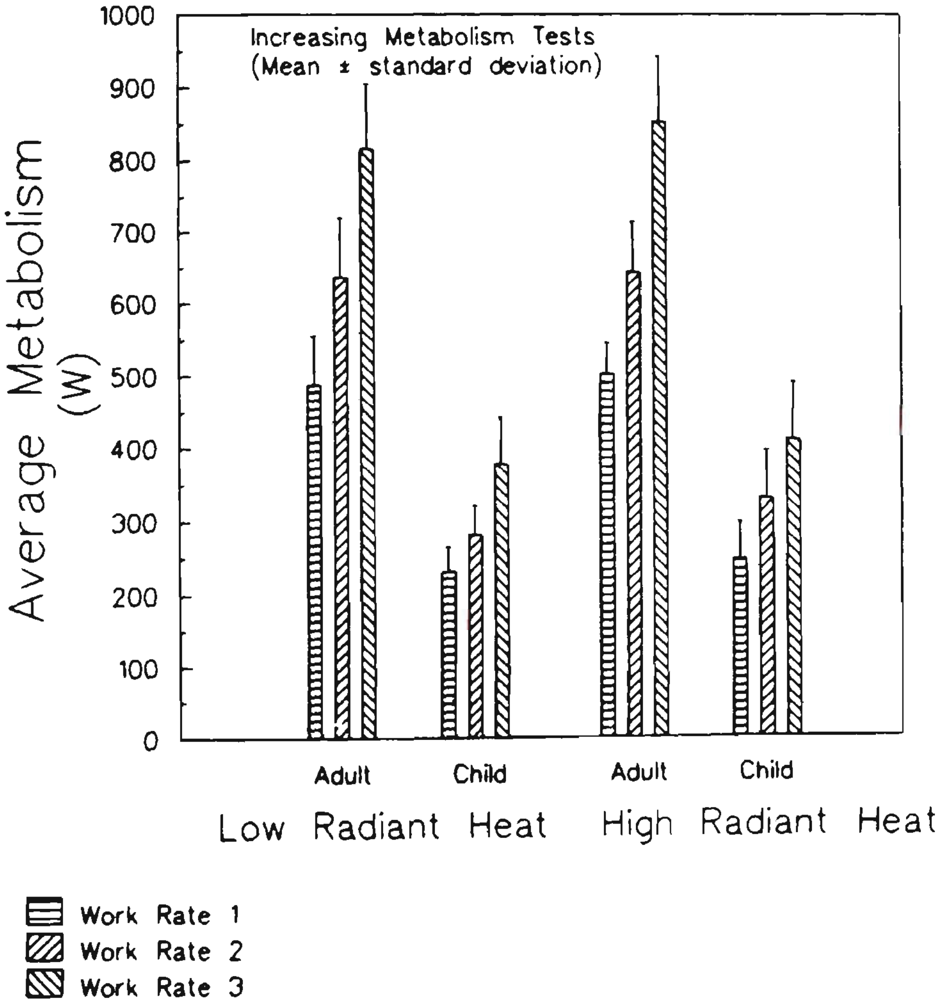


Figure 31 Average metabolism at each work rate for the increasing metabolism experiment in a hot wet climate with radiant heat.

AVERAGE METABOLISM AS A PERCENTAGE OF VO_2 MAXIMUM

There was no significant difference between the groups for percentage of maximum oxygen uptake (Appendix C-15). The average percentage of maximum oxygen uptake was 38% at the first level, 49% at the second level and 64% at the third level of metabolism (Appendix B-13). There was a significant difference in percentage of oxygen uptake between the low and high radiant heat conditions. The high radiant heat condition averaged over both groups was 1% higher at the first level, 3% higher at the second level and 4% higher at the third level compared to the low radiant heat condition. The children increased their percentage of VO_2 maximum in the high radiant condition compared to the low radiant condition significantly more than the adults at the second and third work levels. The children increased by 7% compared to the adults 0% at the second work level and 5% compared to the adults 3% at the third work level (Figure 32).

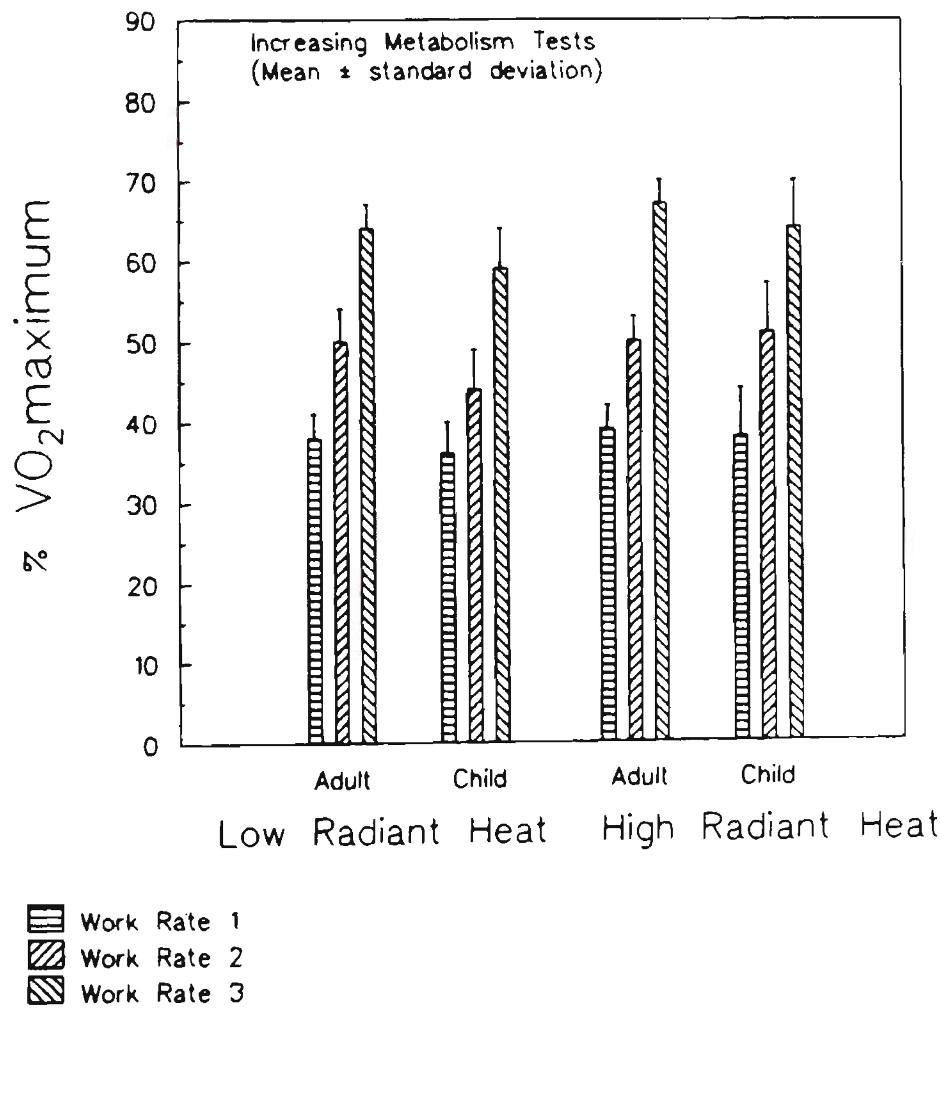


Figure 32 Percentage of VO_2 maximum at each work rate for the increasing metabolism experiment in a hot wet climate with radiant heat.

METABOLIC EFFICIENCY

There was a significant difference between the groups for metabolic efficiency (Appendix C-15). The adult group was 7% more efficient than the children's group at the first work level and 6% more efficient at the second and third work levels (Appendix B-13). There was a significant difference in efficiency between the two levels of radiant heat. The high radiant heat condition averaged between 0.5% and 1.0% less for metabolic efficiency across the three work rate levels compared to the low radiant condition. There was a significant effect of work rate level on metabolic efficiency. Metabolic efficiency increased with each increase in the level of work intensity (Figure 33).

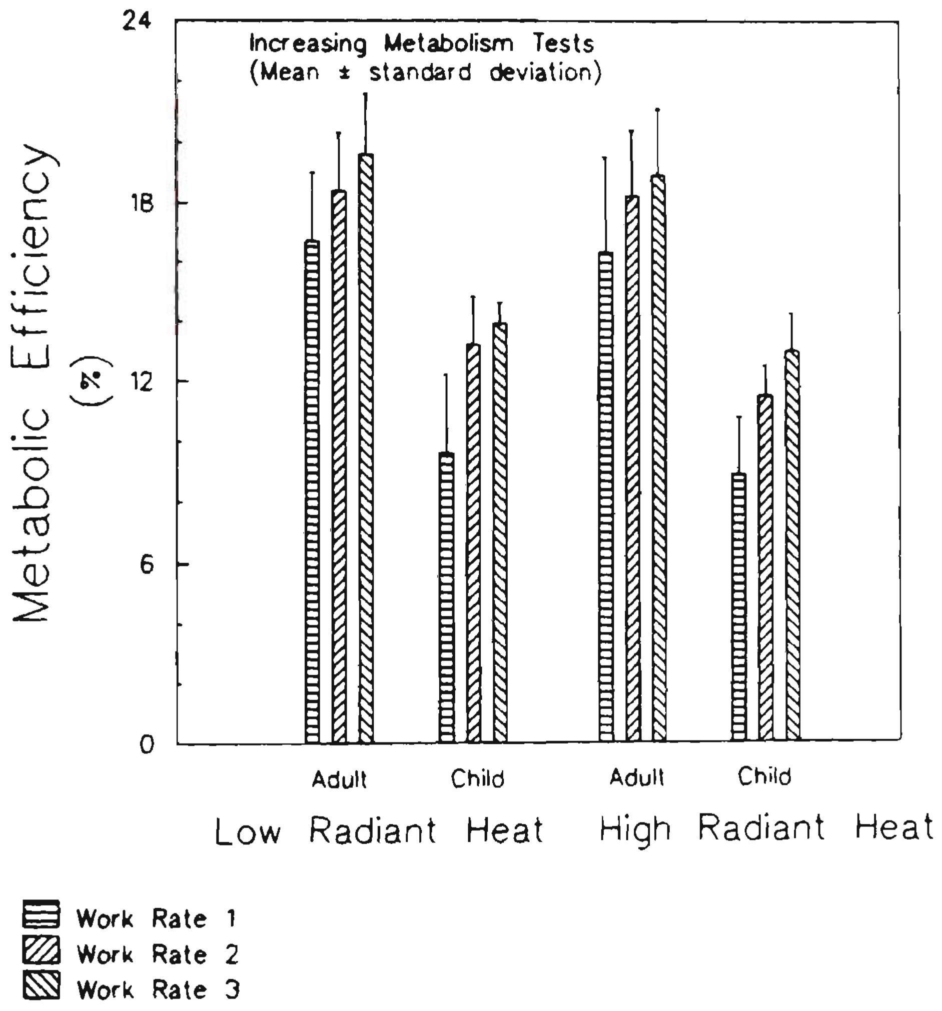


Figure 33 Metabolic efficiency at each work rate for the increasing metabolism experiment in a hot wet climate with radiant heat.

HEAT PRODUCTION

The adult group produced approximately twice as much metabolic heat as the children's group across each of the three levels of metabolism (Table 41). There was a significantly higher heat production for the high radiant heat condition compared to the low radiant heat condition (Appendix C-15). The average increase in heat production for the high radiant heat condition compared to the low radiant heat condition was 5-8% more for the three work intensities. Also there was a significant group by level interaction for heat production. The adult group's heat production increased more between successive levels of work than the children's group.

Table 41 Heat production for the increasing metabolism test in hot wet conditions with radiant heat

Group	Easy Workload (watts)	Moderate Workload (watts)	Hard Workload (watts)
Low radiant#			
Adult*	[1]406±53[2]	519±64	656±68
Child	209±26	234±33	325±58
High radiant			
Adult*	420±35	524±51	690±70
Child	225±52	292±58	357±73

* Significant difference between the groups

\# Significant difference between the two levels of radiant heat

[1] = mean [2] = standard deviation

To compare the relative heat stress between children and adults heat production was divided by body mass. Figure 34 illustrates the lack of a significant difference for relative heat production between the two groups (Appendix C-16). However there was a significant group by level of radiant heat interaction. The children's group average increase in relative heat production between the low and high radiant heat conditions was 11% compared to the adult group's average increase of 3 percent (Appendix B-13).

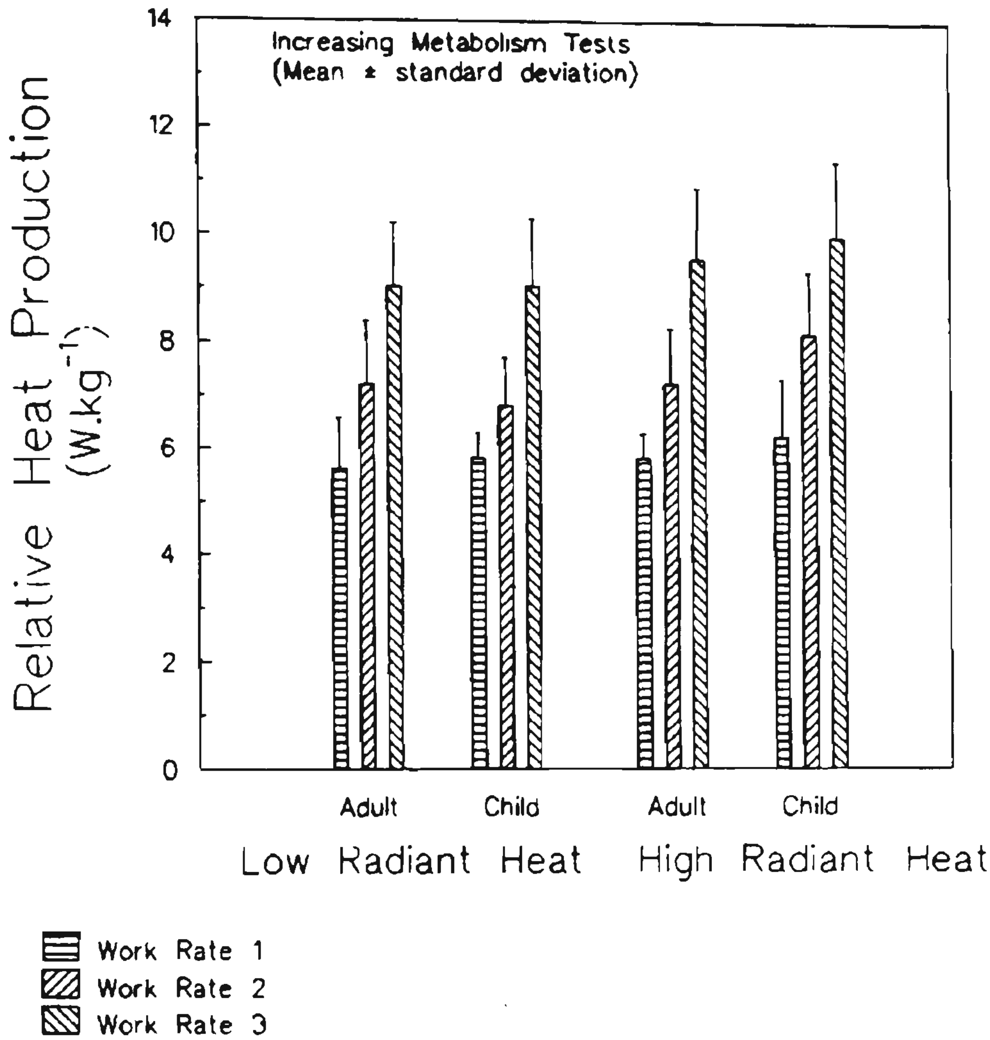


Figure 34 Relative heat production at each work rate for the increasing metabolism experiment in a hot wet climate with radiant heat.

3) EVAPORATIVE HEAT LOSS RESPONSES

SWEAT RATE

There was a significant difference in sweat rate between the two groups (Table 42). The adults sweated approximately twice as much as the children. There was also a significant difference in sweat rate between the two radiant heat conditions. The children's group sweated 25% more and the adult group sweated 14% more in the high radiant condition compared to the low radiant heat condition.

Table 42 Sweat rates for the increasing metabolism test in hot wet conditions with radiant heat

	Sweat Rates	
	Low radiant#	High radiant
Group	$gms.hr^{-1}$	$gms.hr^{-1}$
Adult*	$^{1}780 \pm 106^{2}$	888 ± 154
Child	358 ± 94	472 ± 78

* Significant difference between the groups

\# Significant difference between the two levels of radiant heat

^{1} = mean ^{2} = standard deviation

To realistically compare the sweat rate produced due to the metabolic heat load between children and adults it was considered necessary to compare sweat rates relative to body mass (Figure 35). There was no significant difference between the children and adults for relative sweat rate (Appendix C-16). However there was a significant difference for relative sweat rate between the two radiant heat conditions. The children in the high radiant heat condition produced 26% more sweat in comparison to the low radiant heat condition and the adults produced 14% more sweat in the high radiant condition in comparison to the low radiant condition (Appendix B-14).

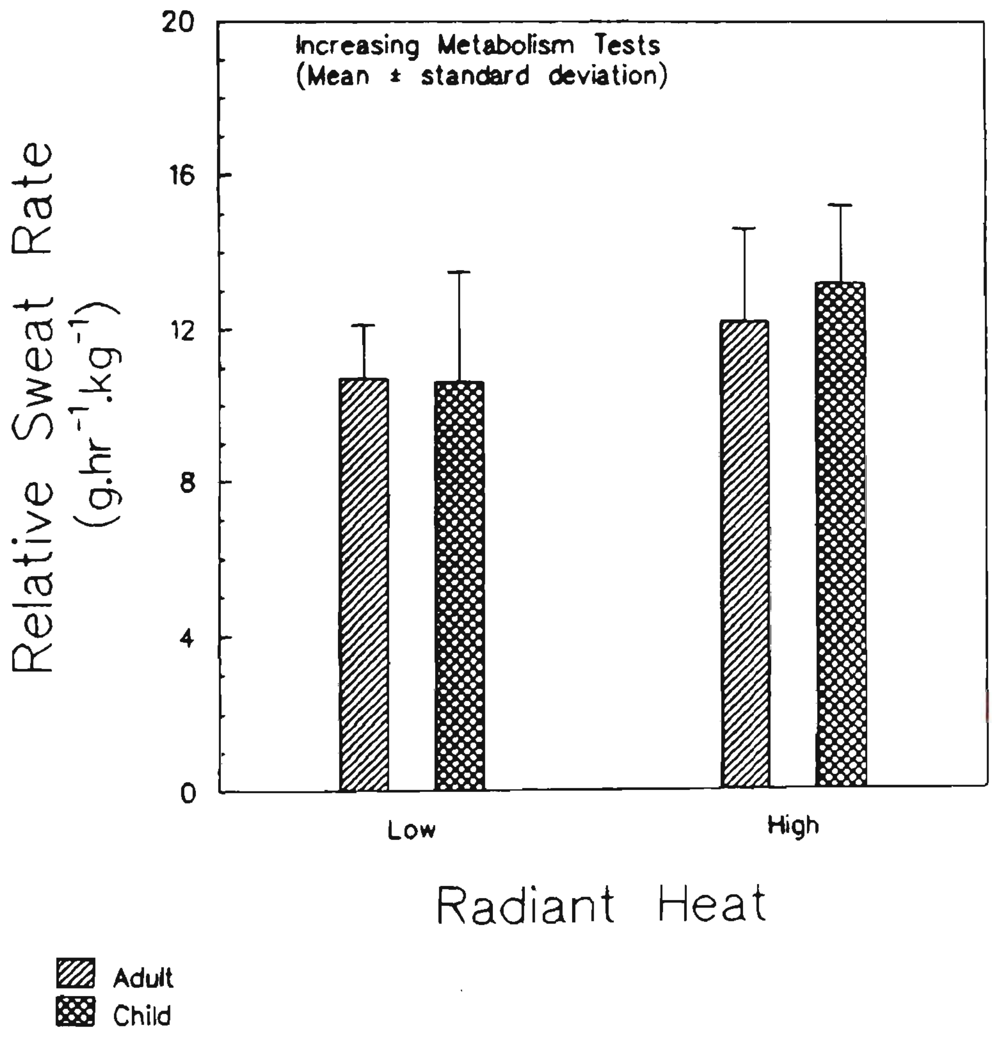


Figure 35 Relative sweat rate for the increasing metabolism experiment in a hot wet climate with radiant heat.

SWEAT HEAT LOSS INDEX

The sweat heat loss index (SHLI) was calculated to standardize for different heat productions between groups and individuals (Figure 36). There was no significant difference between the two groups for the sweat heat loss index (Appendix C-16). However there was a significant difference for the sweat heat loss index between the two radiant heat conditions. The children in the high radiant condition produced a 16% higher sweat heat loss index than they produced in the low radiant heat condition. The same comparison for the adults produced an 11% higher SHLI in the high radiant condition (Appendix B-14).

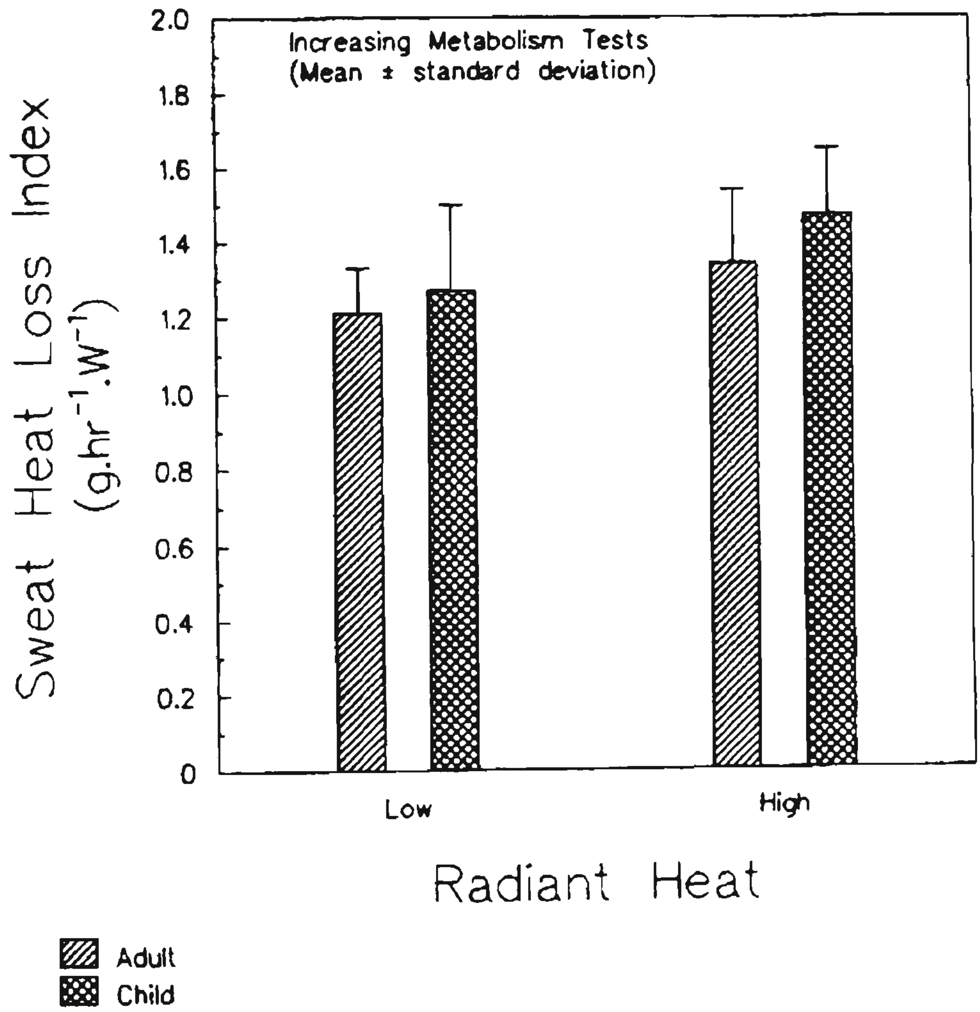


Figure 36 Sweat heat loss index for the increasing metabolism experiment in a hot wet climate with radiant heat.

4) MEAN BODY TEMPERATURES

CORE TEMPERATURE

Figure 37 demonstrates the significant difference in core temperature between the two groups (Appendix C-16). At 5 minutes of exercise the adult group's core temperature (T_c) averaged 37.0°C and the children's group T_c averaged 37.4°C (Appendix B-21). The children's group 0.4°C higher core temperature was maintained between the groups as core temperatures significantly increased over the 30 minutes of the increasing metabolism test. There was also a significantly greater increase in T_c over the thirty minutes of exercise for the high radiant heat condition compared to the low radiant heat condition. The average increase in the high radiant condition was 0.4°C compared to an average increase of 0.2°C in the low radiant condition.

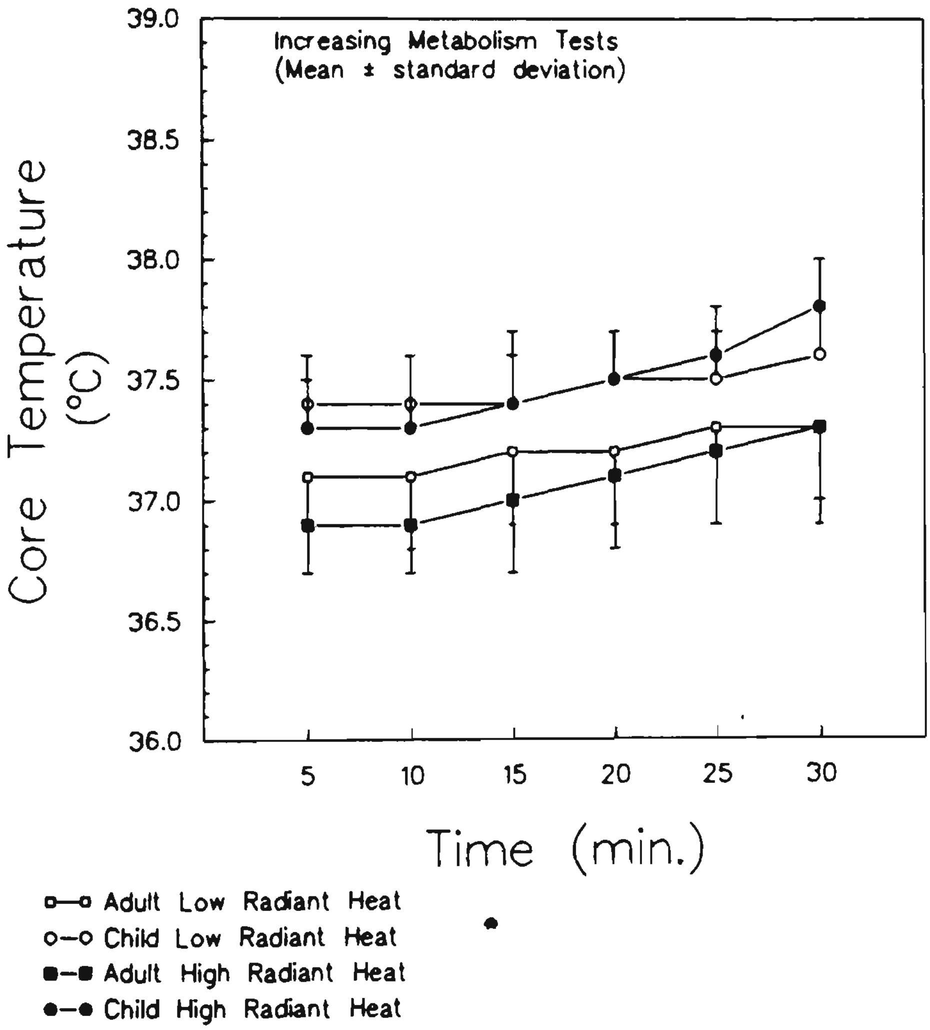


Figure 37 Core temperature for the increasing metabolism experiment in a hot wet climate with radiant heat.

MEAN SKIN TEMPERATURE - NOT EXPOSED TO RADIANT HEAT (T_{sar})

There was a significant difference between the two groups in the skin temperature not exposed to radiant heat (T_{snr}) (Appendix C-16). At 5 minutes of exercise the adult group's average T_{snr} = 33.7°C and the children's group average T_{snr} = 34.2°C. At 15 minutes of exercise the adult group's average T_{snr} = 33.3°C and the children's group T_{snr} = 34.0°C. At 25 minutes the adult group's average T_{snr} = 33.4°C and the children's group T_{snr} = 34.1°C (Appendix B-19). These 0.5-0.7°C differences in T_{snr} between the groups were considered to be significant as they were just greater than the precision of the instrument measuring skin temperature. Subsequently the significant time effect and the significant radiant by time interaction were considered to be trends as the differences in the measurements were less than the precision of the measuring device. Figure 38 illustrates the lack of a significant difference between the T_{snr}'s in the low and high radiant conditions.

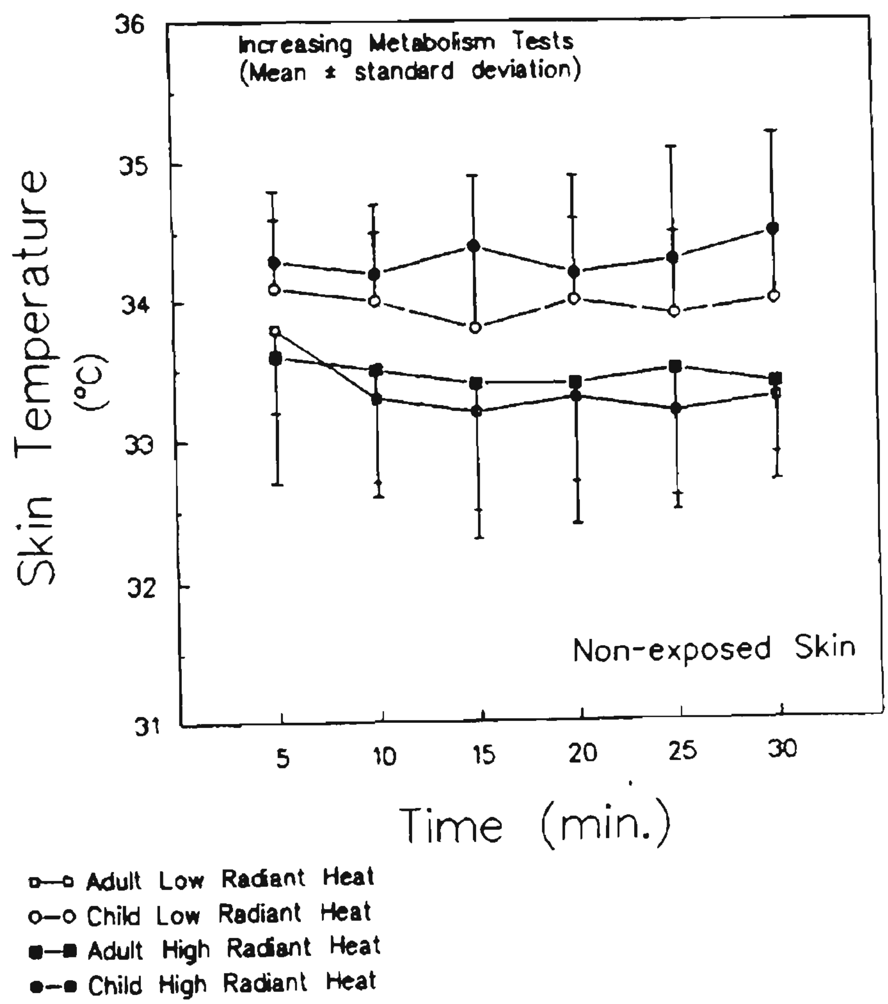


Figure 38 Skin temperature not exposed to radiant heat for the increasing metabolism experiment in a hot wet climate with radiant heat.

MEAN SKIN TEMPERATURE - EXPOSED TO RADIANT HEAT (T_{SER}).

Figure 39 illustrates the significant group by radiant heat interaction for the mean skin temperature exposed to radiant heat (T_{ser}) (Appendix C-17). The children's group T_{ser} was 1.0-1.2°C higher than the adult group in the low radiant heat condition and 1.5-2.0°C higher than the adult group in the high radiant heat condition. This significant interaction effect between group and radiant level is inconsistent as the increase in T_{ser} from the low to high radiant condition was only 0.3°C greater for the children's group compared to the adult group at 5 minutes of the exercise test while it was 1.0°C greater at the end of the exercise test. These differences were generally greater than the precision of the measuring device.

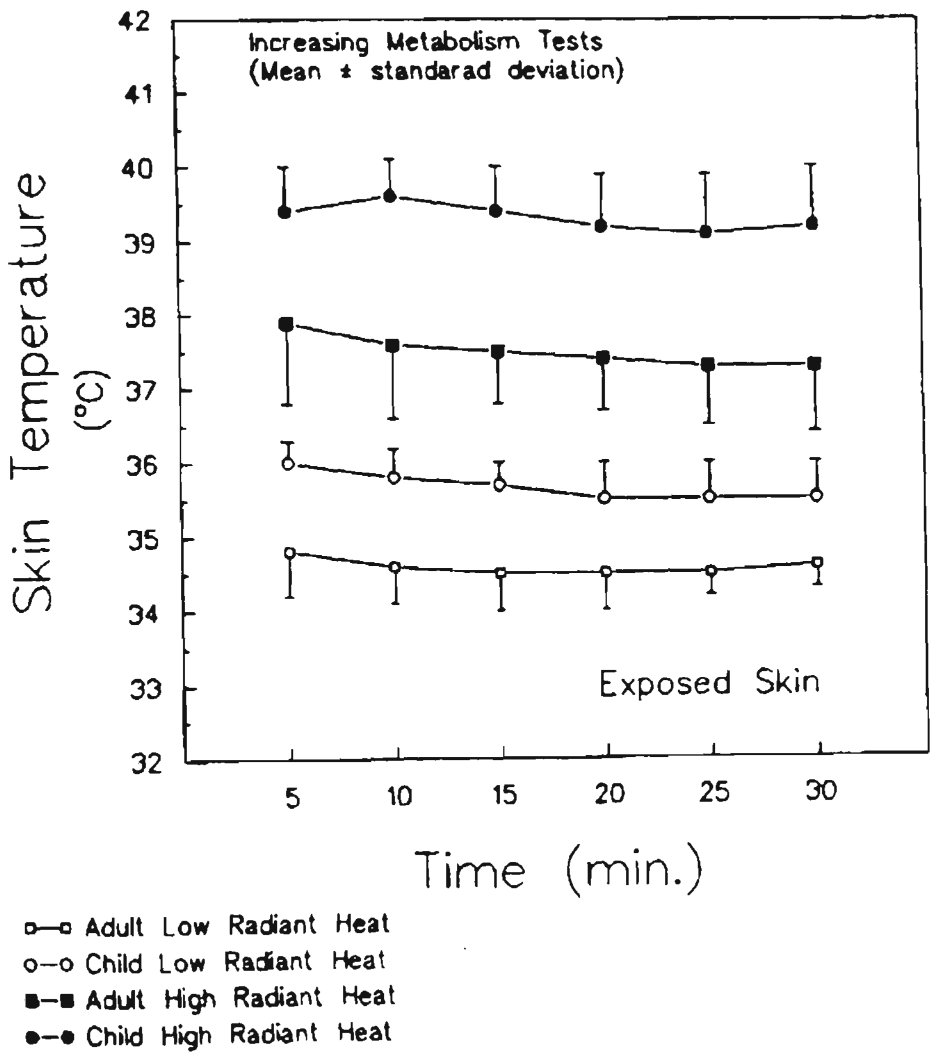


Figure 39 Skin temperature while exposed to radiant heat for the increasing metabolism experiment in a hot wet climate with radiant heat.

5) HEART RATE RESPONSES

HEART RATE

There was a significant difference in heart rate between the two groups (Appendix C-17). At 5 minutes of exercise the adult group's average heart rate was 103 bts.min^{-1} and the children's group average heart rate was 122 bts.min^{-1} (Appendix B-16). The difference in heart rate of approximately 20 bts.min^{-1} between the groups remained the same over time (Figure 40). At 30 minutes the adults group average heart rate was 147 bts.min^{-1} and the children's group average heart rate was 171 bts.min^{-1}.

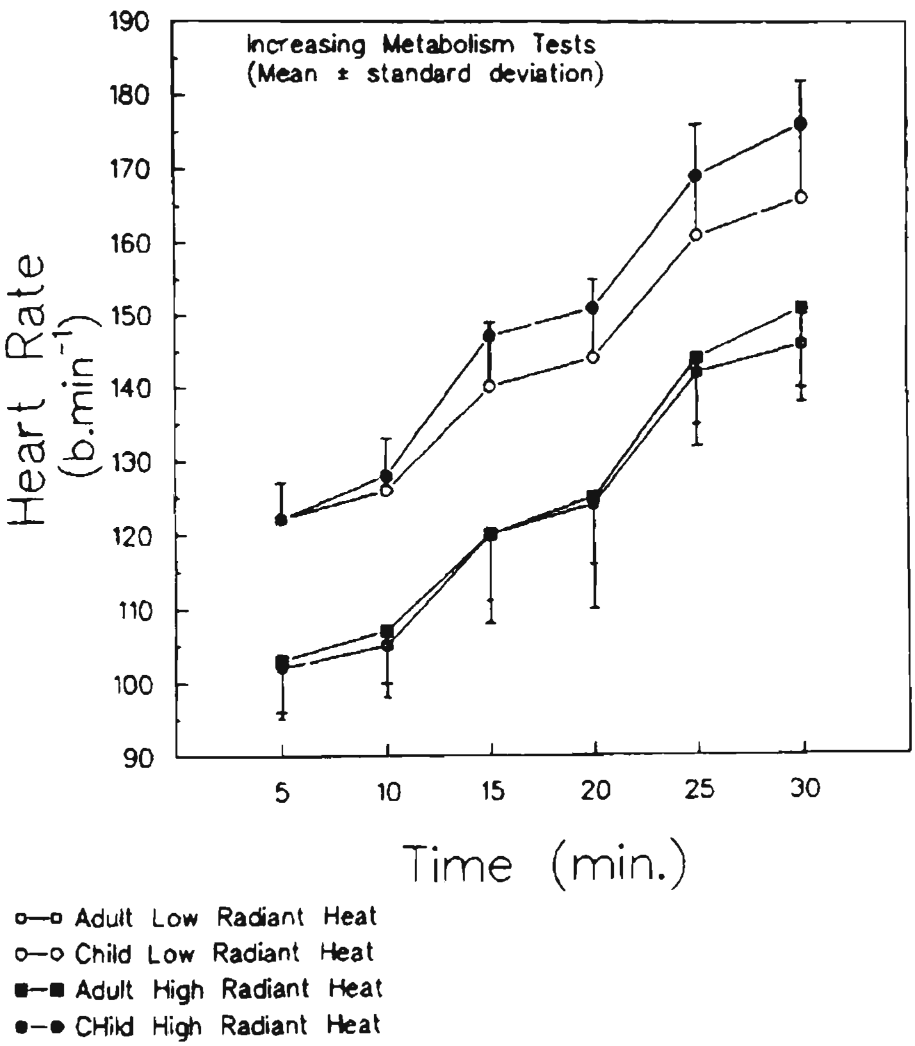


Figure 40 Heart rate for the increasing metabolism experiment in a hot wet climate with radiant heat.

PERCENTAGE OF HEART RATE MAXIMUM

Figure 41 demonstrates a significant difference in the percentage of heart rate maximum between the two groups (Appendix C-17). At 5 minutes of exercise the adult group averaged 55% of heart rate maximum and the children's group averaged 61% of heart rate maximum. At 30 minutes of exercise the adult group averaged 79% of heart rate maximum and the children's group averaged 86% of heart rate maximum (Appendix B-17). At 5 and 30 minutes of exercise there was a similar difference in percentage of heart rate maximum which averaged 6-7% between the two groups.

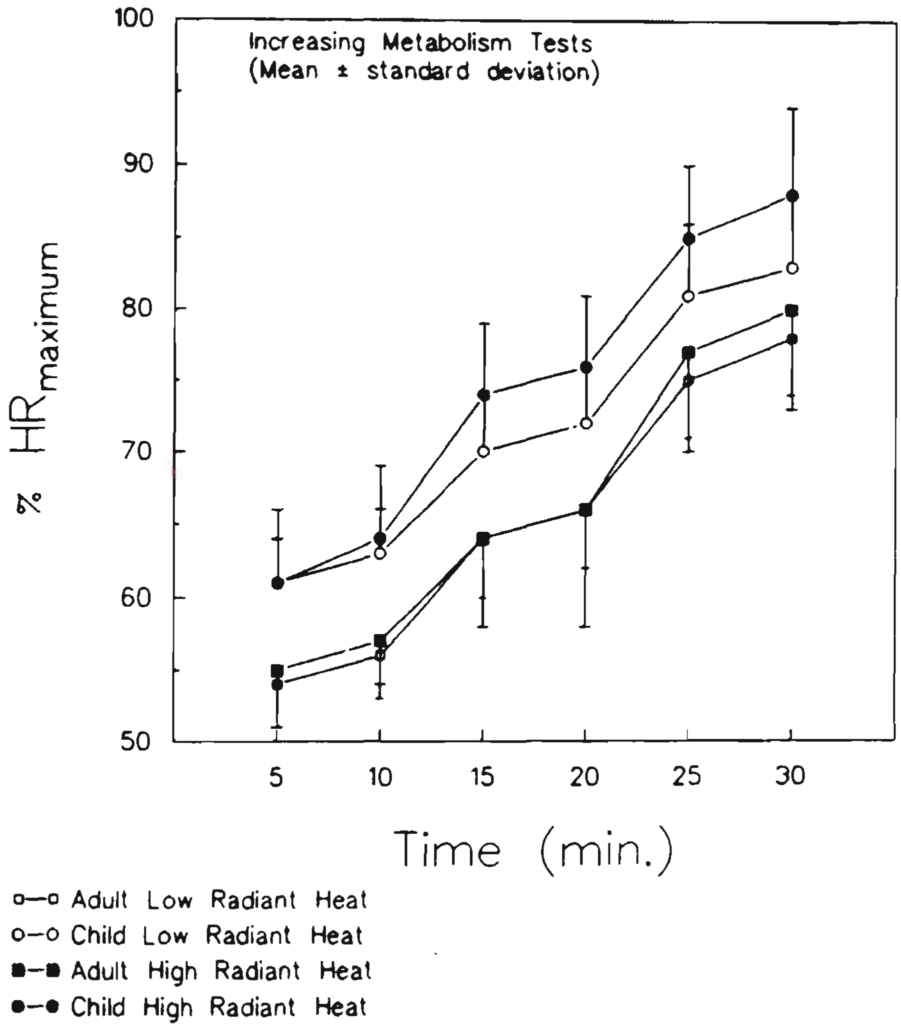


Figure 41 Percentage of heart rate maximum for the increasing metabolism experiment in a hot wet climate with radiant heat.

HEART RATE INDEX

To standardize for the effect on the heart rate of exercising at different percentages of VO_2 maximum, the percentage of heart rate maximum was divided by the percentage of VO_2 maximum. This index was called the heart rate index (HRI). There was a significant difference between the groups with the children exercising at a greater heart rate index than the adults at all exercise intensities (Appendix C-17). At 5 minutes the adult's HRI averaged 1.43 and the children's HRI averaged 1.66. At 15 minutes the adult's HRI averaged 1.31 and the children's HRI averaged 1.56. At 25 minutes the adult's HRI averaged 1.20 and the children's HRI averaged 1.38 (Appendix B-18). Figure 42 also indicates that as the exercise intensity was increased there was a significant decrease in the heart rate index. This decrease was relatively similar between the children and the adults over the three increasing exercise intensities.

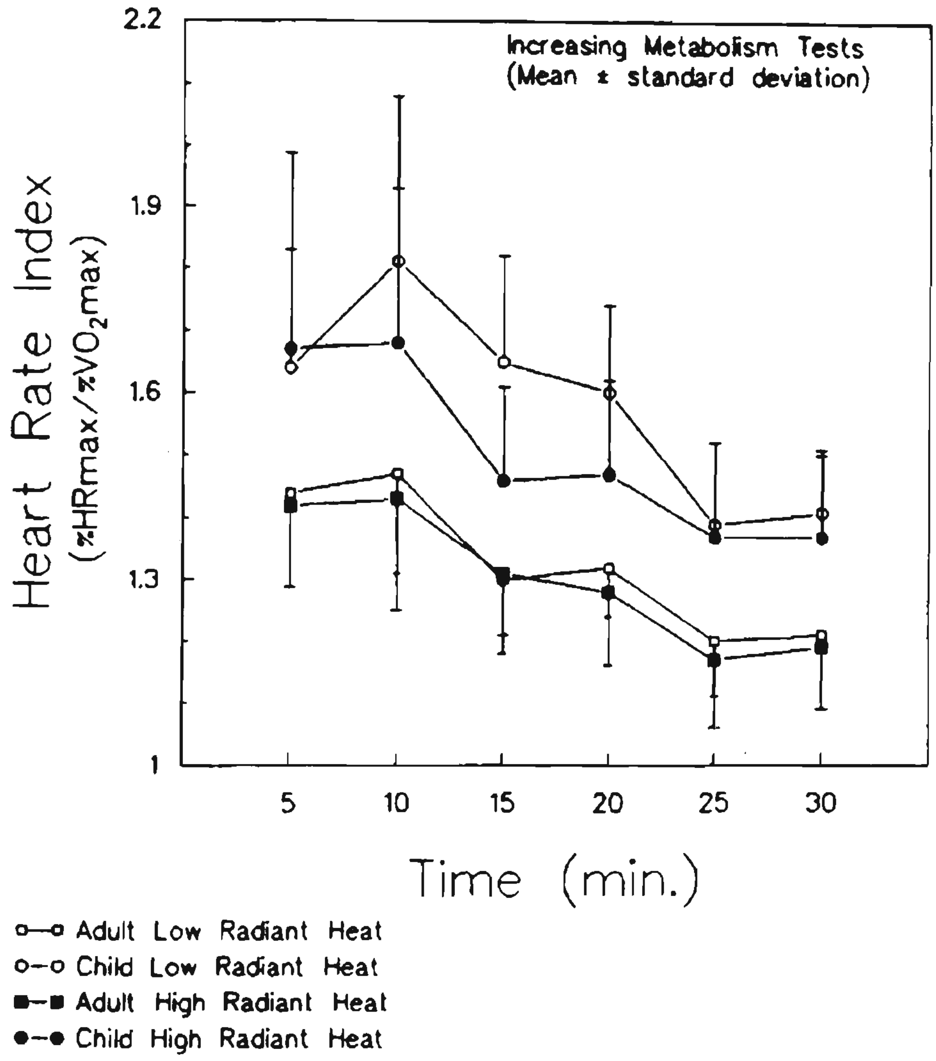


Figure 42 Heart rate index for the increasing metabolism experiment in a hot wet climate with radiant heat.

COVARIATE: SURFACE AREA/MASS RATIO

The analyses of covariance were performed on the dependent variables measured during the first workload. The first 10 minute workload was the most suitable choice as the percentage VO_2 maximum of the adult and children groups were closely similar at both the low and high radiant conditions. Only those dependent variables which had already been shown to be significantly different between the adult and child groups were analysed.

CORE TEMPERATURE AND SURFACE AREA/MASS

Surface area/mass was not significantly correlated with T_c but there was enough common variance to remove the significant difference between the adult and children groups (Appendix C-18).

SKIN TEMPERATURE (T_{ser}) AND SURFACE AREA/MASS

Surface area/mass was not significantly correlated with T_{ser} but there was enough common variance to remove the significant difference between the adult and child groups (Appendix C-18).

SKIN TEMPERATURE (T_{snr}) AND SURFACE AREA/MASS

Surface area/mass was not significantly correlated with T_{snr} but there was enough common variance to remove the significant difference between the groups (Appendix C-18).

PERCENTAGE OF HEART RATE MAXIMUM AND SURFACE AREA/MASS

Surface area/mass was not significantly correlated with the percentage of heart rate maximum but there was enough common variance to remove the significant difference between the children and adult groups (Appendix C-18).

CHAPTER 5

DISCUSSION

This chapter discusses how the substantive variables which were measured in the climate chamber experiments relate to the problem of children having greater thermoregulatory and physiological limitations to exercise in hot conditions than adults. Firstly, the problem is analysed by examining the differences in heat strain responses between children and adults. The heat strain response variables measured were core temperature, skin temperatures, heart rate and sweat rates. Secondly, the relationship between the heat strain response variables and the subject modifiers of heat strain are evaluated. This discussion is presented under the following section headings:

1. Children and adults exercising in hot wet and hot dry environmental conditions without radiant heat.
2. Children and adults exercising at a constant metabolic rate in a hot wet environment with radiant heat.
3. Children and adults exercising at an increasing metabolic rate in a hot wet environment with radiant heat.

PART ONE: CHILDREN AND ADULTS EXERCISING IN HOT WET AND HOT DRY ENVIRONMENTAL CONDITIONS WITHOUT RADIANT HEAT.

AVERAGE METABOLISM

This experiment was designed to achieve equal physiological stress on the children and adults by exercising both experimental groups on a bicycle ergometer at workloads that elicited 50% VO_2 maximum. Equal physiological stress was achieved for the male groups to within 2-3% of 50% VO_2 maximum with no significant differences between the neutral and two hot climates. Equal physiological stress was not achieved for the female groups for all environmental conditions. The female children exercised at a similar percentage of VO_2 maximum to the adults in the neutral climate but at an 8-10% lower percentage of VO_2 maximum than the female adults in the two hot climates. Since the resistance for the workloads was kept the same in the different climates this reduction in metabolism could have been due to a small decrease in the pedal frequency maintained by the children and/or an improved mechanical efficiency. It appears that the female children were more affected by exercise in hot conditions than the male children. This was probably a result of their lower fitness capabilities as measured by VO_2 maximum and a lesser desire to push themselves in uncomfortably hot conditions. Since female adults and children were not exercising at an equal physiological stress any differences between the groups must be interpreted cautiously.

METABOLIC EFFICIENCY

The male children's group had a 6% lower metabolic efficiency than the male adult group. If both groups had an equal aerobic fitness level as measured by VO_2 maximum, the children would have produced more relative metabolic heat than the adults. However, the male children were 10% less aerobically fit than the male adults (53.1 compared to 58.7 $ml.kg^{-1}.min^{-1}$). Since the children were working at a lower relative VO_2

(ie. 50% of 53.1 $ml.kg^{-1}.min^{-1}$ compared to 50% of 58.7 $ml.kg^{-1}.min^{-1}$) but with a 6% lower metabolic efficiency they produced a similar amount of metabolic heat/kg to the adults and this was maintained across the three climates. This is an ideally controlled situation for the comparison of heat strain responses between children and adults. Differences in these heat strain responses can then be related to the different characteristics of children and adults which modify heat stress (except metabolic efficiency). The female children also had a 6% lower metabolic efficiency than the female adults. Similarly to the male children the female children had a 10% lower aerobic fitness than the female adults (44.1 compared to 48.2 $ml.kg^{-1}.min^{-1}$). Consequently when the female children exercised at close to 50% VO_2 maximum they produced a similar relative heat production to the adults in the neutral climate. Reflecting the female children's conservative approach to exercising in the two hot climates they had a lower relative heat production than the adults in these conditions.

In cycling studies nett mechanical efficiency is the most common measurement of efficiency. This value will typically be higher than metabolic efficiency as it subtracts the metabolism which is due to the resting metabolic rate. Another factor which needs to be considered in efficiency studies is the intensity of the work rate. Mechanical efficiency at very low work rates is very low in children. Values as low as 13% and 11% were recorded by Klausen (1985) at work rates which were lower than 16.4 watts. The same children recorded mechanical efficiencies of 19-21% at work rates between 49 and 98 watts. This indicates that the actual intensity of work as a %VO_2 maximum should also be stipulated when comparing efficiencies. In the present study exercise intensity was 50% VO_2 maximum and the metabolic efficiency recorded averaged 12-13% for the female and male children respectfully. Both Naughton (1986) and Lawson (1985) examined gross efficiency of children on a Monark ergometer modified to suit the size of the children. Their definition of gross efficiency equates to the term metabolic efficiency used in this thesis and is the most appropriate term to use in thermoregulation studies as it includes all of the metabolism which produces heat. Naughton (1986) tested 16 eleven year old children at 30%, 60% and 80% VO_2 maximum. The group was a mixture of boys and girls who had similar gross efficiencies. The gross efficiency of 13% for Naughton's subjects when they were tested at 60% VO_2 maximum compares closely with the 12% for the 10 year old girls and the 13% for 10 year old boys who exercised at 50% VO_2 maximum in the present study. The age groups and exercise intensities were closely similar for both studies. The male adults in both studies also had very similar gross efficiencies of close to 19%. Lawson (1985) tested 9, 12 and 15 year old children at 40-50% VO_2 maximum and found that the 9 year old children had an 11% efficiency and the 12 year old children had a 16% efficiency. While the aerobic fitness of these individuals was not documented the results for the 9 year old children agree substantially with the results of this study. The slightly younger age group can be expected to have a lower metabolic efficiency than the subjects in the present study as efficiency has been shown to improve as children mature (Lawson, 1985). The results of previous studies reviewed by Bar-or (1983) revealed that the mechanical efficiencies of children and adults were largely similar on the bicycle ergometer. These studies reviewed by Bar-Or might not be as valid as the more recent studies which were designed for temperature regulation comparisons as they did not closely consider all of the variables which affect the level of efficiency recorded. In particular these studies have not stated the %VO_2 maximum at which the efficiency was measured. Also the subtraction of resting metabolic rate is a proportionally larger value for the children than the adults and nett mechanical efficiency is not the most appropriate term for thermoregulation studies. Finally the modification of the Monark ergometer used in the present study to cater for the smaller size of the children doubles the precision of their work rates and consequently their metabolic efficiency measurements. This allows for a more valid comparison of the metabolic efficiencies of children and adults particularly as the adult's work rate was three times larger than the children's when they were both working at a similar metabolic intensity.

OXYGEN UPTAKE OVER TIME

The oxygen uptake over the 30 minutes of the exercise test was nearly constant in each of the three climates for both the male children and the male adults. The significant difference over time amounted to a 1-2 $ml.kg^{-1}.min^{-1}$ increase in VO_2 over the 30 minutes of the test. The increase in VO_2 was similar for both the children and adult groups and averaged 4%. When the time factor is taken into account this result is in agreement with Asano (1984) who found increases in VO_2 of 8% and 11% in children and adults respectively over 50 minutes of exercise at 60% VO_2 maximum. However these findings are in opposition to the generally accepted concept that a steady state VO_2 can be maintained during prolonged exercise at less than 70% VO_2 maximum (Powers and Howley, 1990). Perhaps the VO_2 drift was a result of an increased effort which imperceptibly increased the pedalling rate as the subjects began to fatigue or it may be due to a general increase in body temperature which in turn increases metabolic rate. While this increase of 4% in VO_2 over the 30 minutes of the exercise test can be considered to be very small it will be an extra contributor to the cardio-vascular drift. The female children and adults exercised at a constant VO_2 for the 30 minutes of the test in each of the three climates. While the statistical analysis states that there was no difference between the neutral and hot climates, Figure 7 indicates that the children show a trend of a reduced VO_2 after 10 minutes of exercise in the hot wet climate compared to the neutral climate which was an average 4% reduction over the 30 minutes of the exercise test. Also there was a trend for a reduced VO_2 in the hot dry climate in comparison to the neutral climate which was an average 3% reduction over the 30 minutes. After having observed the subjects while being tested and on careful examination of the VO_2 levels over time it appears that the adults were very consistent in the production of a constant workload across the three climates and for the 30 minutes of each exercise test. The children however appeared to be more variable than the adults in their application of a constant workload. Klausen (1985) supports this idea with his finding that children did not cycle at the requested RPM on bicycle ergometer tests. Unfortunately he did not comment on how the RPM varied during each exercise test. There does not appear to be a good reason for the VO_2 drift to occur during the 30 minutes of exercise for the male groups and to be absent for the female groups except that the female groups might have subconsciously taken the conservative approach of marginally decreasing the cycling rate as they gradually became more fatigued during the 30 minutes of exercise. To more accurately assess this hypothesis the cycling rate needs to be continuously recorded so that fluctuations in the work rate can be calculated.

HEART RATE RESPONSES

In order to standardise for different maximal heart rates between children and adults the percentage of heart rate maximum was used so that the exercise responses could be more precisely compared between the two groups. In the neutral climate the male children finished the 30 minutes of the exercise test at 70% of heart rate maximum, while the male adults finished at 60% of heart rate maximum. This result indicates that the children used a greater proportion of their heart rate reserve than the adults when both were exercising at the same percentage VO_2 maximum. Davies (1982) supports this position with his study where he exercised athletic children and adults for 60 minutes at 68% VO_2 maximum in neutral conditions. He found that the male children exercised at heart rates which were 16-28 $beats.min^{-1}$ higher than their adult controls. Unfortunately he did not measure maximum heart rates for the two groups but we can speculate that the children used a greater proportion of their heart rate reserve than the adults and that the children exercised at a higher percentage of heart rate maximum. The explanation for this difference between children and adults might be that the children have a proportionally greater amount of blood in the periphery which is a result of their greater skin area to volume ratio (Davies, 1981). Also the children may not be as capable as adults at redirecting their splanchnic blood flow to the exercising muscles at moderate to high work intensities. Both of these possible explanations would necessitate a higher cardiac output and a higher heart rate for the children so that they could maintain both the relatively greater proportion of blood flow to the skin and the muscle metabolism which is related to a set exercise intensity. Davies (1981) believes that this could be the major reason why children cannot perform at the same high percentage of VO_2 maximum for prolonged periods of time as adults. His evidence suggests that while athletic adults can perform at 85% of VO_2 maximum for an hour, athletic children have to reduce their intensity by 10% of VO_2 maximum to exercise for the same duration. The present study also supports this conclusion as the children were exercising at a 10% higher percentage of heart rate maximum when the adults and children were both exercising at 50% of VO_2 maximum. If it is assumed that children and adults can exercise at a high intensity level for prolonged periods at similar percentages of maximal heart rates, then the children will reach these maximal effort intensities at a 10% lower percentage of VO_2 maximum. The reasons for the difference in heart rates between the children and adults as suggested by Davies (1981) is supported by a re-analysis of the present data with the SA/mass ratio being used as a covariate. The difference in heart rate between children and adults was eliminated (Appendix C-7). It appears that the relatively greater volume of blood in the skin as a proportion of the total volume of blood of the children compared to the smaller values for adults is the likely reason for the increased heart rate of the exercising children. The exercising heart rates are different for the three different environments (T_a=22,31,35°C). The increase in the heart rate as the air temperature increases is largely a result of the increased blood flow to the skin which is needed to maintain the skin to air temperature gradient to facilitate heat loss. As the air temperature is increased the skin temperature also increases and passive heat loss via convection is diminished while the evaporative heat loss is increased to maintain an effective heat balance between metabolic heat production and heat loss. The percentage of heart rate maximum also follows the same trend as heart rate and differences between adults and children were again eliminated when the percentage heart rate maximum was covaried against the SA/mass ratio.

When exercising in a hot wet climate (T_a=31°C) both the male children and the male adults increased their percentage of heart rate maximum to 6-7% above that found in neutral conditions. This indicates that children and adults were similarly affected by the hot humid conditions as both groups exercised at a similarly increased percentage of VO_2 maximum. This increase in heart rate for both groups in the hot wet conditions reflects the increased blood flow to the skin which is needed to maintain an effective skin to air temperature gradient; which is needed for a continued convective heat loss.

When exercising in a hot dry climate (T_a=35°C) the male children's percentage of heart rate maximum was considerably more affected than the male adults. After 30 minutes of exercise the children increased their percentage of heart rate maximum to 13% above that produced in the neutral conditions while the adults increased their percentage of heart rate maximum to 6% above that produced in the neutral conditions. This indicates that the children experience a greater degree of cardiovascular strain than the adults as both groups exercised at a closely similar %VO_2 maximum in both environments. The higher % of heart rate maximum recorded by the children under these conditions is likely to be due to a greater increase in skin blood flow or to a poorer venous return to the central circulation. This position that children were more cardiovascularly strained than adults in a hot dry environment is supported by Drinkwater and Horvath (1979). They exercised children in very hot conditions (T_a=48°C) and found that children exercised at a greater percentage of heart rate maximum than adults while both groups were walking at a similar percentage of VO_2 maximum. They believed that this difference was a result of a greater pooling of blood in the periphery of children in comparison to the adults. Since they did not include a neutral temperature exercise experiment it was unclear if this difference in percentage of heart rate maximum between adults and children was greater than the one which was likely to have occurred if the subjects had been tested in a neutral environment. Also there was a large difference in air temperatures between the two experiments and there might be an increased response difference between children and adults as the air temperature increased to more extreme levels. The present study indicates that children are more cardiovascularly strained than adults in hot dry environments down to T_a = 35°C. Further study needs to be conducted in order to more precisely establish the lowest air temperature at which children increase their skin blood flow or venous pooling to a greater extent than adults.

In neutral conditions the female adults averaged 66 percent of heart rate maximum after 30 minutes of exercise. This 6% higher value than the male adults reflects the fact that the females were exercising at a 4% higher percentage of VO_2 maximum. In the two hot conditions the female adults increased their 30 minute exercising heart rate to 72-73% heart rate maximum. This 6-7% increase in percentage of heart rate maximum above those observed in the neutral conditions was similar to that which occurred for the male adults and male children. The female children's group was not evaluated because they exercised at a significantly decreased VO_2 in the two hot conditions. In an attempt to control for the fact that the females exercised at different VO_2's between climates and the male heart rate data might have been affected by small variations in VO_2 between climates and over time the Heart Rate Index was calculated. The HRI was calculated by dividing the percentage heart rate maximum by the percentage VO_2 maximum at which the individual was exercising over the 30 minutes of the exercise test. Since this index standardised the heart rate for both minor and major fluctuations in VO_2 it was appropriate to include the male and female groups together and analyse the total group. There was no effect for gender. The children had a similar heart rate index to the adults in the neutral climate. There was a trend for the children to have a higher heart rate index than the adults but its significance was apparently masked by the large variability in the index.

The children had a higher heart rate index than the adults in the two hot climates with no significant differences for the heart rate index between the two hot climates. Once again the large variability in the heart rate index scores might mask the differences between the two hot climates which was apparent when the percentage of heart rate maximum scores were compared. The higher heart rate index of the children for the hot dry conditions and the greater drift in the heart rate index of the children over the 30 minutes of exercise in these conditions supports the percentage of heart rate maximum data in the contention that the children were more cardiovascularly strained in the hot dry climate than the adults. However, there is a lack of consistency between the two sets of data in the hot wet climate. The greater increase in the heart rate index between the neutral and hot wet conditions for the children is not matched by similar differences in the percentage of heart rate maximum data. It appears that the way the heart rate index was calculated by dividing by the average VO_2 over 30 minutes and the resulting large variability of the index has reduced the precision of this measurement in comparison to the VO_2 and heart rate variables. Consequently the percentage of heart rate maximum data is likely to be more discerning than the heart rate index in the different environmental conditions that were examined.

EVAPORATIVE HEAT LOSS RESPONSES.

Male

As the male groups had a similar relative heat production (Figure 5) they can be considered to have an equal metabolic heat stress. Normally the two groups would be expected to produce equal quantities of sweat in response to equal heat loads but the children had a significantly lower relative evaporative weight loss compared to the adults when exercising in the two hot climates (Figure 10). This evidence is supported by the American Academy of Pediatrics (1982) who concluded from previous studies that the sweating capacity of children was smaller than adults. In the present study as both groups evaporated the large majority of their sweat it can be concluded that the children were losing proportionally less heat by evaporation than the adults. Therefore as the children appear to be in thermoequilibrium they must be losing convective heat at a faster rate than the adults. This is supported by Davies (1982) who found that children exercising in neutral conditions lost 66% of their metabolic heat convectively while adults lost only 50% of their metabolic heat convectively.

Unfortunately the results which occurred in the present study in hot conditions were not supported by the results which occurred in the neutral conditions. The children and adults exercising in neutral conditions had a similar relative evaporative weight loss. Although this is in disagreement with Davies (1982) and the present experiments in hot conditions, it was likely that the large variability in relative evaporation rates obscured the trend for the adults to evaporatively lose more heat than the children. The variability in evaporation rates was likely to be greater in the present study compared to the Davies (1982) experiment because there would be longer delays before evaporation starts at the lower metabolic heat load of the present study and the 30 minutes of exercise doubles the variability in evaporation rates.

The evaporative heat loss index which standardised the evaporative weight loss for differences in heat production between groups and individuals also demonstrated that the children evaporated less sweat in the hot conditions than the adults in proportion to their relative heat production. This index also supports the position that children lose proportionally more heat convectively than adults when $T_a<36°C$. When children and adults were compared on the EHLI with surface area/mass being a covariate there was no difference between the groups. It appears that the children's 32% higher surface area/mass ratio than the adults could be the major reason for their proportionally higher convective heat loss in comparison to their evaporative heat loss. An alternative hypothesis is that children are more efficient at losing heat by the evaporation of sweat than adults. This indicates that children can sweat less than adults but still lose as much heat because of their more efficient evaporation. Haymes (1984) supports both of the above hypotheses with her statement that smaller people will lose heat to the environment more rapidly by both convection and evaporation than larger people because of their larger surface area/mass ratio. Theoretically the rate of losing heat is controlled by the evaporative, convective and radiative coefficients and the skin to air temperature difference. Since the children's and adults' skin temperatures were substantially the same for both groups the differential rate of heat loss will mainly depend on h_c and h_e. According to Kerslake (1972) h_c depends on the characteristic dimension of the individual. Since the children were 79% of the height of the adults (143/180), then their h_c can be assumed to be proportionally larger than the adults according to the formula $h_c=7.2V^{0.6}L^{-0.4}$ (L=0.79) i.e. $h_c=7.95V^{0.6}$ which is calculated as a 10% larger convective coefficient. Due to this size difference h_e will also be 10% larger for the children in comparison to the adults. This theoretical difference between children and adults translates into a greater rate of convective heat loss for the children and also the potential for a greater rate of heat loss through evaporation. However the children do not need to sweat as much as the adults because they have already lost heat convectively at a faster rate. As the need for sweating is decreased in the children, wettedness is also decreased and sweating efficiency is increased, further decreasing the children's need to sweat. The children are thus doubly advantaged by their smaller dimensions.

Female

The comparison of the female groups for relative evaporative heat loss must consider their unequal relative heat production and their different sizes. Since the children produced less relative metabolic heat when exercising in the hot conditions it would be expected that they would also sweat less per kg of body mass. Also the female children's 8% larger surface area/mass ratio in comparison to the adult females should further proportionally decrease the children's relative sweat rate. This was not the case as there was no significant difference between the two groups when they were exercising in the hot conditions. Perhaps the trend for a relatively smaller sweat rate for the children did not reach significance because it was masked by the large variability in sweating between individuals. Also it appears that the female adults have an even larger variability in sweating than the adult males which was perhaps due to the lack of control for the effect of exercising at different stages in their menstrual cycle. The evaporative heat loss index also appears to lack the sensitivity to demonstrate a difference between the two female groups. Perhaps the 8% difference in the surface area/mass ratio between the two groups was not large enough to demonstrate a significant proportional difference in the evaporative heat loss index between the groups as the female children had a smaller advantage than their male counterparts for h_c over the adult females (L=143/166=0.86). Also any differences may have been masked because the variability for the evaporative heat loss index between individuals and groups was too great.

Total Sample

Since the evaporative heat loss index accounts for differences in heat production between individuals and groups it was appropriate to analyse the total sample for any differences on this index. The evaporative heat loss index indicated that there were significant status and sex effects. The children sweated relatively less than the adults and females sweated relatively less than males. Other interactions did occur but it was considered inappropriate to interpret these without further evaluation of the variability of sweating and controlling it strictly for the level of hydration, initial core temperature and the stage in the menstrual cycle for females. It is suggested that the relatively smaller sweat rates of the children and the female groups appears to be related to their smaller size which enables them to lose more heat convectively than adult and male groups when T_a<36°C.

MEAN BODY TEMPERATURES

SKIN TEMPERATURE

There were no significant differences for mean skin temperature between children and adults or between the sexes. The significant climate by time interaction was due to a cooling of the skin in the 22°C environment and a gradual heating of the skin in the 31°C or 35°C air temperatures. The vast majority of this interaction was due to changes in the first 10 minutes of exercise in the ventilated climate chamber after being in a room with a still air environment of approximately 22°C. The female children had a higher T_s than the female adults in the 22°C climate. This was due to three of the children insisting on wearing track suit pants (as opposed to shorts) which would have reduced the cooling effect caused by the 4 m. sec^{-1} air velocity. This increased the average skin temperature for this group in the 22°C environment. In the present study T_s is closely similar for children and adults in both the hot and thermoneutral environments. Drinkwater (1977) also found skin temperatures to be mainly dependent on environmental conditions and to be closely similar between adults and children in hot and very hot conditions. However, Davies (1981) who exercised children and adults at 68% VO_2 maximum in thermally neutral conditions found that the children exercised at skin temperatures which were approximately 3°C higher than the adults. It is hard to rationalise these different results in relation to the present study. The higher exercise intensities, different environmental conditions and the different measurement sites which were used for the mean skin temperature measurements make it hard to directly compare the results of the two studies. Inbar (1978) who examined both prepubertal children and adults exercising at 50% VO_2 maximum in 43°C heat also found that the mean skin temperatures of both groups were similar.

CORE TEMPERATURE

The children's core temperature was significantly higher than the adults in all three climates over the 30 minutes of exercise. On average the children's core temperature, as measured in the ear canal, was 0.4 to 0.5°C higher than that of the adults'. This difference was reasonably consistent over the 30 minutes of the exercise test. There was a gradual increase in core temperatures of 0.1 to 0.3°C over the 30 minutes of the exercise test in hot conditions and this was similar for both children and adults. Since this increase is very small both the children and adults can be considered to be in temperature equilibrium. The children should not be considered likely to suffer heat stress injuries earlier than adults because of their higher initial core temperature. Gullestad (1975) states that the child's resting core temperature is 0.6°C higher than the adults' and that the children's core temperature is raised by a smaller amount to that found for adults when both are exercising at the same percentage of VO_2 maximum. The higher initial core temperature of the children as suggested by Gullestad (1975) is supported by the results of this study and is most likely a consequence of the general relationship that body temperature is inversely related to body mass (Adams, 1989). Haymes (1974) who compared women and girls exercising in 48°C heat also found the girls to have a 0.4°C higher T_{rec} at 30 minutes of exercise but the study was not controlled for the relative exercise intensity of the two groups as they were both walking at 4.8 km.hr^{-1} and on a 5% slope. Davies (1981) who compared children and adults exercising at 68% VO_2 maximum in thermoneutral conditions found the children to have a 0.5°C higher T_{rec} than the adults at the beginning of exercise but after 60 minutes both groups recorded similar results with T_{rec}=38.8-38.9°C.

The ear canal temperature in the present study generally decreased when the subjects exercised at T_a=22°C compared to exercise in the hotter environments. There is likely to be some drainage of the cooler scalp blood past the internal ear canal skin with consequent reductions in the measured core temperature (Marcus, 1973b). McCaffrey (1975) found that T_{ty} generally followed other measurements of core temperature except when there was extreme localised heating and cooling of the facial skin near the ear. Changes in the T_{ty} of up to 0.3 to 0.4°C were produced by water bags at 4°C or 48°C when they were placed on the scalp above the ear. Marcus (1973a) also found changes in T_{ec} of up to 0.4°C due to local radiant heating in the region of the ear. It is suggested that T_{ec} is a suitable measure of core temperature as long as extreme localised heating or cooling in the region of the ear is avoided. In this study the localised cooling effect of air at T_a=22°C and V=4m.sec^{-1} produced a final T_{ec} which was 0.7°C below that found in the T_a=31°C environment. The T_{ec} measured in T_a=22°C was considered to be subject to a major localised cooling effect while exercise in the two hot environments (T_a=31°C and T_a=35°C) were not considered to adversely effect T_{ec} as a measure of core temperature.

To compare past studies with the present one the difference in core temperature measured at the T_{ec} and T_{rec} locations needs to be evaluated. Docherty (1986) studied prepubertal boys exercising at 6 km.hr^{-1} on a treadmill and measured both T_{ec} and T_{rec}. He found that there was a 0.8°C difference between the two measurements of core temperature at both the beginning and end of 60 minutes of exercise. Additionally the T_{ec} had a much faster response time reaching a plateau at 20 minutes of exercise compared to a similar plateau reached at 30 minutes of exercise for the rectal temperature. The final T_{ec} of the Docherty study was 37.4°C at approximately 38% VO_2 maximum and in hot humid conditions (T_a=30°C, Relative humidity=60%). This compares closely with the results of the present study where the subjects were exercising at 50% VO_2 maximum and in hot humid conditions (T_a=31°C, relative humidity=70%). The final T_{ec} measured in these conditions after thirty minutes of exercise was 0.3°C higher than the Docherty (1986) study which can be associated with the children exercising at a 12% higher %VO_2 maximum. When 0.8°C is added to the findings of the present study an estimate of T_{rec}=38.5°C is produced. This is 0.6°C higher than the equilibrium T_{rec} recorded for children (Gullestad, 1975) exercising at 50% VO_2 maximum in neutral climatic conditions.

In the present study the difference in T_{ec} between the adult and children groups was not affected when SA/ mass was used as a covariate. However, when skinfolds and VO_2 maximum were individually used as covariates against T_{ec} the effect of gender was removed but the difference between the children and adults remained unchanged. This could be because the females had greater levels of fat than the males and also a lower aerobic fitness. These two factors could each heat up the females more quickly. It is hypothesised that the females heated up more quickly mainly due to their lower specific heat which was a result of their greater level of fatness in comparison to their male counterparts. The effect of a lower aerobic fitness was perhaps an indirect one in that it was also closely associated with higher levels of fat.

COVARIATE - SURFACE AREA/MASS

It was apparent that the SA/mass ratio was linked to two of the thermoregulatory variables that responded differently for children and adults exercising in neutral and hot conditions. Using the SA/mass ratio as a covariate eliminated the differences between adults and children on heart rates and the evaporative heat loss index, but had no effect on differences for the heart rate index and ear canal temperature. SA/mass was not covaried against mean skin temperature as there appeared to be no differences between children and adults on this dependent variable.

PART TWO: CHILDREN AND ADULTS EXERCISING AT A CONSTANT METABOLIC RATE IN HOT WET ENVIRONMENTAL CONDITIONS WITH RADIANT HEAT.

AIR TEMPERATURE AND HUMIDITY

The air temperatures in the climate chamber were the same for both groups but the relative humidity averaged 6% higher for the children compared to the adults over the 40 minutes of the exercise tests. This higher humidity could be expected to reduce the maximal evaporative capacity of the children in comparison to the adults. When the relative humidity was converted to a water vapour pressure it was 7% higher for the children at an average air temperature of 33°C. This would translate into a 7% reduction in E_{max} if h_e and mean skin temperatures remained the same for both groups. However the children had a theoretically 10% greater h_e and a 0.8°C higher mean skin temperature than the adults. These differences indicate that the E_{max} should be calculated separately for each group. In fact, it was calculated that on average the E_{max} of the adults was 5% lower than the value calculated for the children.

i.e. $E_{max} = h_e \times (P_s - P_a)$

Child $E_{max} = 273 \times (5.32 - 3.82) = 399 W.m^{-2}$
when T_s = 34°C and humidity = 76% at T_a = 33°C

Adult $E_{max} = 248 \times (5.09 - 3.56) = 379 W.m^{-2}$
when T_s = 33.2°C and humidity = 70% at T_a = 33°C

These calculations indicate that the children will be less limited than the adults for losing heat by evaporation. The major reason for their larger E_{max} was their higher h_e and higher skin temperatures. However this does not indicate the cardiovascular cost that might be incurred by the children at this higher humidity. Kamon (1983) suggested that there is a one BPM increase in heart rate for every 0.13kPa increase in water vapour pressure. Since the water vapour pressure was 0.26kPa higher in the climate chamber for the children in comparison to the adults it can be calculated that the children will exercise at a heart rate which is increased by two BPM in comparison to the adults. This calculation assumes that the children will be affected by humidity in a similar way to the adults. Even if the children have a slightly different response to the adults it appears that the higher humidity experienced by the children in the climate chamber would generate a very small increase in the cardiovascular cost compared to that experienced by the adults. Some caution must be included with this interpretation as Kamon's subjects exercised at light intensities in comparison to the moderate intensities undertaken in the present experiment.

WORK RATE, METABOLISM AND HEAT PRODUCTION

The experiment was designed to enable both the children and adult groups to work at the equal physiological stress of 50% VO_2 maximum. However, while both groups worked at a statistically similar metabolic rate for the 30 minutes of the test there was a 4% difference in their relative intensities. The adult's metabolism averaged 50% of VO_2 maximum and the children's averaged 46% of VO_2 maximum. The children were also 6% less efficient than the adults and this proportionally increased their metabolic heat load. Since the children and adults were equal in aerobic fitness and the children were exercising at a lower percentage of VO_2 maximum, their lower efficiency compensated and enabled both groups to work at the equal metabolic heat stress of 7.3 $W.kg^{-1}$. Heat production depends on the aerobic fitness of the individuals, intensity of exercise and their metabolic efficiency. To satisfactorily compare children and adults they should have equal aerobic fitness and be exercising at the same percentage of VO_2 maximum. Once these conditions are satisfied then it appears that children will have a higher relative heat production than adults because of their lower exercising efficiency.

EVAPORATIVE HEAT LOSS RESPONSES

The relative sweat rates of the children were practically the same as the adults in both the low and high radiant heat conditions. At air temperatures below 36°C children can be expected to lose heat convectively faster than adults. In the first section of this study it was concluded that the children were losing proportionally less heat by evaporation than the adults. Therefore as the children appeared to be in thermoequilibrium they were losing convective heat at a faster rate than the adults. This idea was supported by Davies (1982) who found that children exercising in neutral conditions lost far more of their metabolic heat convectively than their adult controls. While the air temperatures were different between the two studies both still had air temperatures that were below mean skin temperatures which favours a convective heat loss. If there was no radiant heat, children would be expected to sweat less. The application of radiant heat to the back and the lateral aspect of the left upper arm (approximately 20% of the skin's surface) caused children to absorb radiant heat at a faster rate than the adults. This increased radiant heat gain appears to have neutralised the convective heat loss advantage of the children.

Children with their smaller surface area would proportionally absorb less radiant heat. Blum (1945) calculated that 270 watts of radiation was absorbed by the average adult in a temperate climate. If this level of radiation was incident upon the average 10 year old's skin area of $1.1m^2$, the child would absorb 165 watts of radiant heat. However, when this absorbed radiant heat was converted to a radiant heat load per kg of body mass, the children's relative radiant heat load was $165/32 = 5.2\ W.kg^{-1}$ which was considerably more than the adult's relative heat load of $270/69 = 3.9\ W.kg^{-1}$. These calculations indicate that the children have a 33% greater radiant heat stress because of their larger SA/mass ratio. The anthropometric data used in the above calculations was taken from Tanner's (1978) average height and weight data for 10 year old and eighteen year old males. In the present study the increased radiant heat load of the children appears to be balanced by their greater convective heat loss. It appears that the exposure of radiant heat to 20% of the skin's surface must be close to the break even point for matching heat loss and heat gain by these two heat exchange mechanisms. It could be hypothesised that when more than 20% of the skin's surface is exposed to radiant heat that the children will have a greater heat stress in comparison to the adults. Conversely, when less than 20% of the skin's surface is exposed, children will maintain their heat loss advantage over adults in air temperatures which are less than 36°C. In general the skin's surface which absorbs radiant heat depends on the sun's latitude and altitude and varies between 5% (sun overhead) and 25% (facing the sun with sun's altitude at 90^0) (Kerslake, 1972).

The hypothesis that radiant heat exposure to 20% of the skin's surface is the break even point for heat exchange between convection and radiation in a hot wet climate with an air temperature of 31-33°C has two limitations which need further investigation. Firstly, the infra-red heaters can not beam the radiant heat at an even intensity to all parts of the exposed skin. Secondly, the radiant heaters are likely to have a different heating effect to the sun's spectrum which heats the skin to different depths depending on the wavelength of the radiation.

The sweat heat loss index which standardised for different quantities of heat production between the subjects also supports the above findings on relative sweat rates with both the children and adults producing closely similar sweat heat loss indices in the low radiant condition. The higher radiant heat load produced higher SHLI's and this was increased by a similar percentage for both children and adults. The SHLI was used instead of the EHLI used in the first experiment because the radiant heat produced large beads of sweat on the backs of both children and adults and sweat dripped on the floor. Consequently a large amount of the sweat was not evaporated. To evaluate the effectiveness of sweating between adults and children the drippage should be collected over a naphthalene tray. It is quite possible since the children have a greater h_e than the adults that they will also have a higher sweating efficiency than the adults. While this argument indicates possible errors in the measurement of the effectiveness of the sweat rate between children and adults, the SHLI still gives a good indication of the heat stress on an individual as sweat rate is directly proportional to increases in core and skin temperatures (Nadel, 1971). Even though different subjects were used in the first and second experiments the male children could be compared because they had very similar levels of aerobic fitness as measured by their respective VO_2 maximums. Despite the lower relative exercising intensity of the children in the second experiment ($7.3\ W.kg^{-1}$ and $7.9\ W.kg^{-1}$

respectively) these children produced a greater relative sweat rate. While these two experiments are hard to compare directly due to the different heat loss indices that were used it can be claimed that the greater sweat rates in proportion to the lower heat productions were largely a result of the radiant heat loads experienced in the second experiment.

MEAN BODY TEMPERATURES

CORE TEMPERATURE

The ear canal temperature of the children's group was 0.3°C higher than the adult group at the beginning of the exercise test. This difference between the adults and children remained relatively the same for the duration of the 40 minute exercise tests and was similar to the 0.4-0.5°C difference between the adults and children experienced in the first experiment in the hot wet conditions without radiant heat. The high radiant heat condition had no additional effect on the T_{ec} in comparison to the effect of the low radiant condition. However when SA/mass was covaried against the core temperature the mean difference between the children and adults was removed. This did not occur in the first experiment and it is difficult to rationalise the different results of the two analyses. In conclusion it can be said that there were minimal differences in T_{ec} between children and adults as both remained in thermoequilibrium at a level which was predominantly related to their relative metabolic heat production and their body size. Further experiments need to be planned to verify that the initial differences in core temperature between adults and children will not lead to an earlier predisposition to heat injury of children.

SKIN TEMPERATURE (T_{sar})

The skin temperature not exposed to radiant heat varied between 33°C and 34°C for the children exercising in the hot wet environment of this study. On the face and upper arm sites the adults recorded a 0.8°C lower mean T_s than the children. On the lower back and upper arm sites the adults recorded a 1.7°C lower mean T_s than the children in the first 10 minutes of exercise without the application of radiant heat. The skin temperatures at the face and upper arm sites were not affected by the application of radiant heat to other skin sites. In general it can be claimed that children will have a higher mean skin temperature than adults when exercising in a hot wet climate without radiant heat. The increased skin temperature of children in comparison to adults broadens the skin to air temperature gradient and subsequently elevates the rate of convective heat loss. This result differed from the non significant differences found between the mean skin temperatures of the children and adults which occurred in section A. The two experiments however, measured the skin temperatures with different instruments. Placing a probe on the skin and securing it with tape creates a microenvironment which does not allow the children or adults to fully respond to the cooling effect of the air moving past the body. In part A of the studies in hot wet conditions the mean skin temperature was approximately 34°C for both the children and the adults. It could be surmised that there was a greater local evaporation by the adults in part B which maintained the skin at a lower temperature in comparison to the children's skin temperature. In line with this argument the application of the tape over the probe in part A might not have allowed the evaporation of sweat to cool the adult's skin more than the children's when they were both exercising in a hot humid environment. To fully understand the differences and similarities between children's and adults' skin temperatures exercising in hot wet environments a more systematic experiment needs to be planned. Both local skin temperatures measured by infra-red thermometry and local sweat rates should be sampled over a large number of sites on the body so that the differences between adults and children along with the possible reasons for these differences can be established. Finally when T_{snr} was covaried with SA/mass the differences in T_{snr} between the children and adults were eliminated. It could be hypothesised that the greater use of convective heat loss by the children reduced their evaporation rate in comparison to the adults which enabled the children to maintain a slightly higher mean skin temperature.

SKIN TEMPERATURE (T_{ser})

While the radiant heat flux considerably raised the temperature of the exposed skin the effect was similar for the adults and the children in that the initial 1.7°C difference between them was maintained under both low and high radiant heat fluxes. High radiant heat loads raised the T_{ser} above the core temperature. The laws of thermodynamics predict that this high T_{ser} will further heat up the body core as the blood's convective heat movement will be from the skin to the body core. This will only occur for the 20% of the skin which is exposed to the radiant heat. The high skin temperature also increased the skin to air temperature gradient and an increased rate of convective heat loss will occur and the evaporative heat loss can also be increased as the water vapour pressure difference between the skin and the air is increased over the skin's surface. Thus while there is a radiant heat input to the body core there is also an increased rate of convective heat loss and the potential for an increased rate of evaporation. The children with their higher skin temperatures appear to be losing more heat by convection and less by evaporation of sweat in comparison to the adults. In the present situation the children had a similar metabolic heat load and a relatively larger radiative heat load than the adults. When both groups were exposed to the high radiant heat load they both increased their sweat rates by the same proportion in relation to the sweat rates in the low radiant heat condition. This indicated that the children's further increased radiant heat load had been matched by an increased rate of convective heat loss. The increased skin temperatures of the children in the high radiant condition increased the air to skin temperature gradient and proportionally increased the rate of convective heat loss. It is apparent that the greater convective heat loss of children in comparison to adults occurs on the areas of the skin exposed and those not exposed to radiant heat. In summary, the extra radiative heat load of the children has been dissipated by their greater rate of convective heat loss.

HEART RATE RESPONSES

Since the children had a significantly higher maximum heart rate than the adults it was most appropriate to compare the percentage of heart rate maximum as this will give an estimate of the heart rate reserve of the children and the adults exercising at the same intensity. The children exercised at a significantly higher percentage of maximum heart rate than the adults. At 15 minutes they exercised at a 6% higher percentage of heart rate maximum and this general trend continued for the rest of the exercise test. At 40 minutes the children were 7% higher on the percentage of heart rate maximum compared to the adults. However, compared to the males in part A exercising in hot wet conditions there was a smaller difference between the adults and children. If the children in part B of the study had been working at 50% VO_2 maximum instead of 46% then the difference between the adults and children was likely to be similar to that found in part A (10% difference in the percentage of heart rate maximum). Once again when SA/mass was covaried with the percentage of heart rate maximum the differences between the children and adults were eliminated. This result along with the similar result in part A of the study further reinforces the contention that children have a relatively greater volume of blood in the skin as a proportion of the total volume of blood compared to the smaller values for adults and this is the likely reason for the smaller heart rate reserve recorded by the exercising children. There was a significantly greater cardiovascular drift in the high radiant condition compared to the low radiant condition for both the children and adults. This implies that the larger radiant heat load caused an increase in the skin blood flow so that the additional radiant heat could be dissipated from the skin. The resulting smaller venous return produced a smaller stroke volume and a higher heart rate resulted so that the constant work rate could be maintained.

The heart rate index was calculated to standardise for differences in $\%VO_2$ maximum between the groups. The children's higher HRI in comparison to the adults supported the contention that children exercised at a higher percentage of heart rate maximum and had a smaller heart rate reserve when both groups were exercising at similar standardised intensities. The children's HRI drifted more than the adults over the 40 minutes of the exercise test. This difference between the adults and children was supported by the HRI in part A where the HRI of the children drifted more than the adults when they were exercising in the two hot climates. The greater increase in the percentage of heart rate maximum over time in the higher radiant heat condition was not supported by the HRI data. Since the HRI had a large variability and some of the trends did not reach significance it is felt that more credence should be placed on the percentage of heart rate maximum results. The calculation of the HRI could be improved in the future by averaging heart rates and VO_2's over each 2-3 minutes and then calculating the index rather than averaging the VO_2 over the full test as was the case in this study.

COVARIATE SURFACE AREA/MASS

It was apparent that the SA/mass ratio was linked to three of the four thermoregulatory variables that responded differently for children and adults exercising in hot wet conditions with radiant heat. Using the SA/mass ratio as a covariate eliminated the differences between adults and children on percentage of heart rate maximum, core temperature and the skin temperatures not exposed to radiant heat, but had no effect on the difference between children and adults for T_{scr}. SA/mass was not covaried against relative sweat rates or the SHLI as there appeared to be no differences between children and adults on these dependent variables.

PART THREE: CHILDREN AND ADULTS EXERCISING AT AN INCREASING METABOLIC RATE IN HOT WET ENVIRONMENTAL CONDITIONS WITH RADIANT HEAT.

The children and adults tested in this experiment were the same ones used for the previous experiment. The two groups were similar for VO_2 maximum, sum of skinfolds and the ponderal index. However, their maximum heart rates and surface area per mass ratios were significantly different. The children's heart rate maximum averaged 12 beats higher than the adult value and their SA/mass ratio was 30% greater.

AIR TEMPERATURE AND HUMIDITY

The climate chamber generated hot wet climatic conditions for the adult and children groups. The air temperature was the same for both groups, but the humidity was significantly higher for the children's group. It was 12% higher in the first 10 minutes and 7% higher in the last 20 minutes of the exercise test. Robinson (1945) has found that thermoequilibrium is maintained while walking in 34°C and 91% humidity. Walking can be considered to utilise approximately 35% of VO_2 maximum. The children from the present study were exercising at 38% of VO_2 maximum in a less severe environment than the one utilised by Robinson (1945). ie T_a = 31-32°C and relative humidity equal to 90%. While it should not be a problem to dissipate the metabolic heat (38% of VO_2 Maximum) in the first 10 minutes of the exercise test, the extra humidity is likely to have an added cardiovascular cost for the children. Kamon (1983) claimed that the cardiovascular cost of humidity is an increase of 1 bpm for every extra 0.13 KPa of water vapor pressure above 1.7 KPa. In the first 10 minutes of exercise the water vapor pressure for the adults was 3.50 KPa and for the children was 4.04 KPa. This equates to a predicted cardiovascular cost of 14 bpm for the adults and 18 bpm for the children. This theoretical difference of 4 bpm in heart rate between the children and adults can be considered to be small particularly at the low work rates that occurred in the first 10 minutes of the exercise test.

In the last 20 minutes of the exercise test the 7% higher humidity of the children's exposure converted to a 10% higher water vapor pressure. This would normally translate into a 10% lower E_{max} but the children have a theoretically 10% greater h_e and higher skin temperatures than the adults. When E_{max} was calculated separately for the two groups the children surprisingly had a theoretically greater E_{max} than the adults. This calculation was only appropriate for the 80% of the skin not exposed to radiant heat.

i.e. $E_{max} = h_e \times (P_s - P_a)$

Child

h_e = 273, P_s = 5.38kPa (T_{snr}=34.2°C), P_a = 3.77KPa (T_a=33°C)

Therefore E_{max} = 273x(5.38 - 3.77) = 440 $W.m^{-2}$

Adult

h_e =248, P_s = 5.14KPa (T_{snr}=33.4°C), P_a = 3.41KPa (T_a=33°C)

Therefore E_{max} = 248x(5.14 - 3.41) = 429 $W.m^{-2}$

The calculation of E_{max} can also be performed using the temperature (T_{ser}) of the skin which was exposed to high levels of radiant heat (approximately 20% of the skin's surface). The E_{max} of the children was theoretically 14.3% higher than the adults in these conditions.

i.e. $E_{max} = h_e \times (P_s - P_a)$

Child

$T_{ser} = 39°C$, $P_s = 6.99KPa$.

Therefore $E_{max} = 273x(6.99 - 3.77) = 879\ W.m^{-2}$.

Adult

$T_{ser} = 37.5°C$, $P_s = 6.45KPa$.

Therefore $E_{max} = 248x(6.45 - 3.41) = 753\ W.m^{-2}$.

In conclusion when both environmental conditions and skin temperatures were taken into consideration the children have a greater evaporation potential than the adults. In the last 20 minutes of exercise the reduced humidities of both groups should relate to a reduced cardiovascular cost in comparison to the first 10 minutes. Kamon's (1983) formulae needs to be applied cautiously as the subjects of the present study were working at moderate and high workloads while Kamon's subjects were working at low intensities. While the possible humidity related cardiovascular differences between the children and adults has not been systematically evaluated, it is anticipated that the effect will be small (less than the 4 bpm estimated in the first 10 minutes of the exercise test).

WORK AND METABOLISM

The 10 minute workload levels were designed to be easy, moderate and hard. There were no main effects for differences on the percentage of VO_2 maximum between the groups; the average %VO_2 maximum for both groups being 38% at the first work level, 49% at the second work level and 64% at the third work level. However, exercise in the high radiant heat condition averaged over both groups resulted in a 3-4% higher %VO_2 maximum for the last 20 minutes of the test compared to the low radiant heat condition. This difference was predominantly a result of the children who exercised at a 5-7% higher %VO_2 maximum in the last 20 minutes of the test in the high radiant heat compared to the low radiant heat condition. Also the children were 5-7% less efficient than the adults when they exercised at the three work levels of this test. The lower efficiency infers that the children will produce relatively more metabolic heat than the adults when they are both exercising at the same relative intensity as long as they have similar aerobic fitness levels. Overall there were no significant differences in relative heat production between the adults and children. In the low radiant condition the children and adults produced similar amounts of metabolic heat due to the children exercising at a 5-7% lower %VO_2 maximum and having a 6% lower metabolic efficiency. However, in the high radiant condition the children produced significantly more metabolic heat/kg than the adults. This relatively larger variability in VO_2 of the children compared to the adults particularly between the high and low radiant conditions was most likely a result of the children varying their cycling rates as the resistances were maintained at the same level in both radiant heat conditions. These results support the contention that children are a lot more variable in the application of constant work loads than adults (Klausen, 1985).

EVAPORATIVE HEAT LOSS RESPONSES

In line with the similar relative heat productions between the children and adults there were no significant differences in the relative sweat rates between the two groups. However, there was a trend for the children to have a higher relative sweat rate in the high radiant heat condition when compared to the adults (8.2% higher). This trend appears to be in line with the greater relative heat production of the children (average 10.8% higher) in the high radiant heat condition.

The sweat heat loss index was used to standardise for the mean different metabolic heat productions between the groups; especially for the children in the high radiant heat condition. Again there were no significant differences between the groups. However, there was a trend for the children to have a higher sweat heat loss index than the adults (9.7% higher) in the high radiant condition. While the SHLI will correct for the different heat productions to some extent it does not make allowance for the different delay times for the initiating of sweating which occur at the beginning of exercise. It can be expected that exercise at higher metabolic rates will heat the body up at a faster rate and initiate sweating earlier; thus proportionally causing a greater sweat rate due to sweating at the required rate for a longer period of time. When moving from the low radiant condition to the high radiant condition the children increased their relative sweat rate by 26% and increased their SHLI by 16%. At the same time the adults increased their relative sweat rate by 14% and their SHLI by 11%. The greater difference between the relative sweat rate and the SHLI for the children in comparison to the adults reflects the children's greater heat production in the high radiant condition compared to the low radiant condition. The adult group had a very similar heat production in both the high and low radiant conditions and only a small difference between the percentage increase in their relative sweat rate and the percentage increase in their SHLI.

In general as the two groups were producing similar metabolic heat loads and also similar SHLI's, these results indicate that while the children were absorbing a greater radiant heat load they were also convectively losing heat at a faster rate than the adults. Children and adults appear to have an equal potential to produce sweat in these conditions, but this does not indicate the cardiovascular cost of losing this heat and whether the cardiovascular cost differs between children and adults.

MEAN BODY TEMPERATURES

CORE TEMPERATURE

The children had a 0.4°C higher core temperature than the adults at the beginning of exercise. The response of both groups to an increasing metabolism test was similar in that the 0.4°C difference in T_c remained constant over the 30 minutes of exercise. Core temperature increased over time due to the increased metabolic rate at each of the three work levels. The high radiant heat condition increased core temperature at a faster rate than the low radiant heat condition. This is difficult to interpret as the children and adults exercised at an average 3-4% higher percentage of VO_2 maximum and had an increased metabolic heat load in the high radiant condition over the last 20 minutes. The additional increase in T_c of 0.2°C for the high radiant condition during the 30 minutes of the exercise test is most likely a result of this increased metabolism and not a result of the higher levels of radiant heat. In general the children can be expected to absorb a greater relative radiant heat load than the adults and it appears that this increased heat load was neutralised by the children's ability to lose heat convectively at a faster rate.

MEAN SKIN TEMPERATURE (T_{snr})

The children had a higher T_{snr} than the adults, but the 0.7°C average difference between the groups is only a small amount above the 0.5°C precision of the measuring instrument. This 0.7°C difference is almost identical to the 0.8°C difference found in the first experiment in part B. The skin temperature did not appear to be affected by the increasing level of metabolism in this experiment and was controlled predominantly by the climatic conditions. The higher skin temperatures of the children plus the children's theoretically larger h_c enabled them to lose significantly more heat convectively than adults. The above differences between the groups can be considered indicative of 80% of the skin's surface which were not exposed to radiant heat. The higher humidity conditions experienced by the children was not expected to produce large differences in skin temperatures between the children and adults. The Berger and Grivel (1989) formulae which calculates T_s for different humidities predicted that only a 0.2°C difference in T_{snr} could be expected between the two groups.

MEAN SKIN TEMPERATURE (T_{ser})

While there was a significant response for the children's T_{ser} to increase more between low and high radiant heat when compared to the adults, this response was small (0.5°C - 0.8°C higher). This result was not consistent with the first experiment in Part B which demonstrated similar increases for adults and children. However both the children and the adults exercising in the high radiant condition as opposed to the low radiant condition increased their T_{ser} by about 3°C in both the constant metabolism and increasing metabolism experiments with radiant heat. It appears that there was a fair amount of variability in T_{ser} over time. This variability can be explained by small changes in posture affecting the distance of the skin from the radiant heat source. Allowing for small changes in posture of the children compared to the adults it is not unreasonable to assert that mean T_{ser} variations would need to be considerably greater than the 0.5°C precision of the measuring device before significant differences could be established. Following this argument the children and adults have responded in a similar way. The children however, have recorded a 1-2°C higher mean T_{ser} than the adults; which was most likely due to their higher initial skin temperature before being exposed to radiant heat. To fully investigate these small changes in skin temperature a more precise study needs to be developed with a larger number of skin sites being measured and with the distance of the radiant heat source from the skin being more closely controlled. The higher humidity experienced by the children is likely to increase their skin temperature by a very small amount [i.e. 0.2°C calculated by the Berger and Grivel (1989) formulae].

HEART RATE RESPONSES

As the level of metabolism increased at each work level, the difference in percentage of heart rate maximum remained the same between the adults and children. The children had heart rates which were 6-9% higher than the adults throughout the 30 minutes of exercise. This was similar to part one of experiment B where both groups exercised at close to 50% of VO_2 maximum and there was a 6-7% difference in the percentage of heart rate maximum. Children also had a higher heart rate index than the adults at the three levels of exercise intensity. As the intensity of metabolism was increased there was a similar reduction in the heart rate index for both groups. This occurs because as the intensity of exercise increases the percentage of heart rate maximum does not change in the same proportion as the percentage of VO_2 maximum. A more suitable heart rate index could have been calculated by subtracting the resting heart rate and resting metabolism before calculating the ratio. This more suitable index was not used in this study as the resting information was not collected.

In conclusion the heart rate index and the percentage of heart rate maximum both indicated that the children were exercising with less cardiovascular reserve than the adults at intensities between 38% and 64% of VO_2 maximum. At the higher intensity the adults recorded 79% of heart rate maximum and the children recorded 86% of heart rate maximum. If the intensities were increased to even higher levels the 7% difference in the percentage of heart rate maximum between children and adults could be expected to be maintained and the children would experience cardiovascular limitations before the adults. The children are likely to reach 90% of heart rate maximum at approximately 68% of VO_2 maximum. This was the level of intensity that Davies (1981) had children maintain for one hour in neutral climatic conditions. Approximately 70% of VO_2 maximum could be expected to be the upper limit of cardiovascular strain that prepubertal children could maintain for extended periods of time in neutral climatic conditions. However, at this intensity in hot conditions the children are likely to fatigue very quickly owing to the cardiovascular drift exceeding 90% of heart rate maximum.

COVARIATE - SURFACE AREA/MASS

The differences between children and adults in the first 10 minutes of the test on T_{sur}, T_{scr}, T_c and the percentage of heart rate maximum was removed by using SA/mass as a covariate. This indicated that the children's size was a likely reason for the differences between adults and children exercising in hot humid conditions with radiant heat. Since the children appear to thermoregulate adequately when exercising in these hot climatic conditions the above differences in core and skin temperatures should not put children at a thermoregulatory disadvantage. However their higher percentage of heart rate maximum when exercising at the same percentage of VO_2 maximum indicates that children should terminate exercise sooner than adults when exercising at intensities above 60% of VO_2 maximum, especially when they are exposed to hot wet climatic conditions with radiant heat. Children have a smaller heart rate reserve and will reach limiting heart rates sooner than adults.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The purpose of this study was to examine the problem:
Do children have greater thermoregulatory and physiological limitations to exercise in hot environmental conditions than adults?
Hot conditions were defined as air temperatures between 30-36°C. These conditions were chosen because they are commonly occuring in Australia and it was of considerable concem that a proportion of the children playing sport in these conditions could suffer from a range of heat disorders. The problem was analysed by examining the differences in heat strain responses between children and adults. The heat strain response variables measured were core temperature, skin temperatures, heart rate and sweat rate. Finally the relationship between the heat strain response variables and the subject modifiers of heat strain were evaluated. This chapter is presented in the following sequence.

1) Summary of procedures.
2) Summary of findings.
3) Conclusions.
4) Implications of the conclusions.
5) Recommendations for further study.

1) SUMMARY OF PROCEDURES

This research study was conducted in two parts.
Part A: Children and adults exercising in hot wet and hot dry environmental conditions without radiant heat.
Part B: Children and adults exercising in hot wet environmental conditions with radiant heat.
The aim of part A of the study was to compare the physiological and thermoregulatory responses of children and adults exercising in neutral and commonly occuring hot wet and hot dry environmental conditions without radiant heat.
The aim of part B of the study was to compare the physiological and thermoregulatory responses of children and adults exercising in hot wet environmental conditions with either high or low levels of radiant heat at a constant work rate or at an increasing work rate with easy, moderate and hard intensities.

PART A: CHILDREN AND ADULTS EXERCISING IN HOT WET AND HOT DRY ENVIRONMENTAL CONDITIONS WITHOUT RADIANT HEAT.

SUBJECTS

The subjects for this part of the thesis were 16 physical education students (9 men and 7 women) from Victoria University of Technology and 15 prepubertal children (8 boys and 7 girls) aged between 9 and 11 years from Ascot Vale Primary School.

PHYSIOLOGICAL VARIABLES MEASURED

Anthropometric measurements obtained were height, weight and the sum of skinfolds (calf, thigh, abdomen and triceps). Surface area/mass and the ponderal index were also calculated. Cardiovascular fitness was measured by an incremental effort to volitional exhaustion on a Monark cycle ergometer. Oxygen uptake was continuously measured so that both VO_2 maximum and the work rate at 50% VO_2 maximum could be established.

Three thermoregulatory exercise tests were performed for 30 minutes on a Monark cycle ergometer at 50% VO_2 maximum. The climate chamber was regulated to produce neutral, hot wet and hot dry environmental conditions:

i) Neutral T_a = 22°C, Relative humidity = 50%.

ii) Hot wet T_a = 31°C, Relative humidity = 73%.

iii) Hot dry T_a = 35°C, Relative humidity = 28%

A large fan blowing air at 4 $m.sec^{-1}$ onto the front of the subjects in the hot wet and hot dry environmental conditions produced an effective temperature of 25.0°C for each of the two hot climates. The dependent variables which were measured during these thermoregulation exercise tests were core temperature, skin temperatures, heart rate and evaporation rate.

DATA COLLECTION PROTOCOLS AND METHODS

The following measurements were repeated for each of the three 30 minute exercise tests in the climate chamber.

i) Mass to the nearest 5 grams before and immediately after the exercise test so that sweat loss, relative evaporative weight loss and the evaporative heat loss index could be calculated.

ii) VO_2 was measured at each 5 minute interval throughout the 30 minute exercise test. The following derived variables were subsequently calculated: %VO_2 maximum, metabolic efficiency and relative heat production.

iii) Heart rate was measured by ECG at each 5 minute interval during the 30 minute exercise test. This enabled the %heart rate maximum and the heart rate index to be calculated.

iv) Core temperature was measured by a thermistor probe inserted into the ear canal at each 5 minute interval during the 30 minute exercise test.

v) Mean skin temperatures were measured at 5 minute intervals by skin thermistors placed on the thigh, sternum and upper arm.

ANALYSIS

The following statistical analyses were performed using the SPSSX package and a main frame HP3000 computer.

i) Anova by sex and status on the following subject modifiers of heat stress: Sum of skinfolds, VO_2 maximum, SA/mass and Ponderal index.

ii) Manova by status, climate and time on the dependent variables measured on the subjects undergoing the thermoregulatory exercise tests: VO_2, heart rate, % heart rate maximum, heart rate index, T_{ec} and mean T_g. These analyses were mainly conducted separately for the male and female groups.

iii) Manova by status and climate on the dependent variables measured on the subjects undergoing the thermoregulatory exercise tests: %VO_2 maximum, metabolic efficiency, relative heat production, relative evaporative mass loss and the evaporative heat loss index. These analyses were mainly conducted separately for the male and female groups.

iv) Mancova using Sum skinfolds, SA/mass and VO_2 maximum as covariates to establish the relationships between these subject modifiers of heat stress and the dependent variables that were significantly different between the child and adult groups.

PART B: CHILDREN AND ADULTS EXERCISING IN HOT WET ENVIRONMENTAL CONDITIONS WITH RADIANT HEAT

The research design of Part B of this thesis was subdivided into two experiments; each relating to exercise in hot wet environmental conditions with exposure to radiant heat.

Experiment one examined the effect of exercising at a constant work rate selected to elicit 50% VO_2 maximum.

Experiment two examined the effect of exercising at increasing work rates selected to elicit easy, moderate and hard metabolic intensities.

SUBJECTS

The subjects for this part of the thesis were ten male physical education students from Victoria University of Technology and ten male prepubertal children aged between 9 and 11 years from Ascot Vale Primary School.

PHYSIOLOGICAL VARIABLES MEASURED

The anthropometric variables measured were the same as for part A.

The cardiovascular fitness measurement was also the same as for part A.

Four 30 or 40 minute thermoregulatory exercise tests were performed in hot wet conditions in the climate chamber.

The first two tests, designated as experiment one compared the thermoregulatory and physiological responses of children and adults exercising at approximately 50% VO_2 maximum in hot wet environmental conditions with either low or high levels of radiant heat. The subjects exercised for ten minutes without radiant heat to establish baseline data and then continued for an additional 30 minutes with either low (T_g=37°C) or high (T_g=49°C) levels of radiant heat.

The second pair of tests, designated as experiment two compared the physiological and thermoregulatory responses between children and adults exercising for 10 minutes at each of easy, medium and hard exercise intensities in hot wet environmental conditions under either low (T_g=37°C) or high (T_g=49°C) levels of radiant heat. The two radiant heaters were attached to stands which were placed 55cm from the left upper arm and 55cm from the lower back. The Corrected Effective Temperature was 28.0°C in the low radiant condition and 31.5°C in the high radiant condition. These temperature index scores included a wind velocity of 4m.sec^{-1} directed at the front of the subjects.

The dependent variables which were measured during these exercise tests were core temperature, skin temperatures, heart rate and sweat rate.

DATA COLLECTION PROTOCOLS AND METHODS

The following measurements were repeated for each of the two 40 minute exercise tests and each of the two 30 minute exercise tests in the climate chamber.

i) Mass was measured to the nearest 5 grams before and immediately after the thermoregulatory exercise test so that sweat loss, relative sweat loss and the sweat heat loss index could be calculated.

ii) VO_2 was measured at each 5 minute interval throughout the 30 and 40 minute exercise tests. The following derived variables were subsequently calculated from these measurements: %VO_2 maximum, metabolic efficiency and relative heat production.

iii) Heart rate using a sportstester was measured at each 5 minute interval during the 30 and 40 minute exercise tests. This enabled the %heart rate maximum and the heart rate index to be calculated.

iv) Core temperature was measured by a thermistor probe placed in the ear canal at each 5 minute interval during the 30 and 40 minute exercise tests.

v) Mean skin temperature of the skin not exposed to radiant heat (T_{snr}) was measured by an infrared surface measuring thermometer and calculated to be the average of the cheek and right upper arm sites. Measurements were taken at each 5 minute interval during the 30 and 40 minute exercise tests.

vi) Mean skin temperature of the skin exposed to radiant heat (T_{ser}) was measured by a infrared surface measuring thermometer and calculated to be the average of the two lower back and left upper arm sites. Measurements were taken at each 5 minute interval during the 30 and 40 minute exercise tests.

ANALYSIS

The following statistical analyses were performed using the SPSSX package and the HP3000 mainframe computer.

i) Anova by status on the following subject modifiers of heat stress: Sum of skinfolds, VO_2 maximum, SA/mass and Ponderal index.

Experiment one: Constant metabolism exercise in hot wet environmental conditions with low and high levels of radiant heat.

ii) Manova by status, radiant level and time on the dependent variables measured on the subjects undergoing the thermoregulatory exercise tests: VO_2, heart rate, %heart rate maximum, heart rate index, T_{ec}, mean T_{snr} and mean T_{ser}.

iii) Manova by status and radiant level on the dependent variables measured on the subjects undergoing the thermoregulatory exercise tests: %VO_2 maximum, metabolic efficiency, relative heat production, relative sweat mass loss and the sweat heat loss index.

iv) Mancova using SA/mass as a covariate to establish the relationship between this subject modifier of heat stress and the dependent variables that were significantly different between the children and adult groups.

Experiment two: Increasing metabolism exercise in hot wet environmental conditions with low and high levels of radiant heat.

v) Manova by status, radiant level and time on the dependent variables measured on the subjects undergoing the thermoregulatory exercise tests: VO_2, heart rate, %heart rate maximum, heart rate index, T_{ac}, mean T_{sur} and mean T_{ser}.

vi) Manova by status and radiant level on the dependent variables measured on the subjects undergoing the thermoregulatory exercise tests: %VO_2 maximum, metabolic efficiency, relative heat production, relative sweat mass loss and the sweat heat loss index.

vii) Mancova using SA/mass as a covariate to establish the relationship between this subject modifier of heat stress and the dependent variables that were significantly different between the children and adult groups.

2) SUMMARY OF FINDINGS

CHILDREN AND ADULTS EXERCISING IN HOT WET AND HOT DRY ENVIRONMENTAL CONDITIONS WITHOUT RADIANT HEAT

The following similarities and differences were observed between the children and adult groups exercising in neutral and commonly occuring hot wet and hot dry environmental conditions without exposure to radiant heat.

METABOLIC EFFICIENCY

The male children had a 6% lower metabolic efficiency than the male adults exercising at approximately 50% VO_2 maximum.

The female children also had a 6% lower metabolic efficiency than the female adults exercising at approximately 50% VO_2 maximum.

The adults were very consistent at producing a constant work rate over the 30 minutes of each thermoregulatory exercise test and across the three climates. The children, however appeared to produce a more variable work rate both between the three climatic conditions and over time when they attempted to apply a constant workload in the same manner as adults.

HEART RATE

The male children recorded 70% of heart rate maximum after completing 30 minutes of exercise at 50% VO_2 maximum in $T_a = 22°C$, while the male adults recorded 60% of heart rate maximum at the end of the same exercise test. This result indicated that the children used a greater proportion of their heart rate reserve than the adults when both were exercising at the same intensity.

The differences between adults and children on the percentage of heart rate maximum were eliminated when this dependent variable was covaried against the SA/mass ratio.

The male children and the male adults both increased their percentage of heart rate maximum to 6-7% above that found in neutral conditions when they where exercising in a hot wet climate (T_a=31°C).

The male children's percentage of heart rate maximum was considerably more affected than the male adults when they where both exercising in a hot dry climate (T_a=35°C). The children after 30 minutes of exercise increased their percentage of heart rate maximum to 13% above that produced in the neutral conditions while the adults increased their percentage of heart rate maximum to 6% above that produced in the neutral conditions. The higher percentage of heart rate maximum recorded by the children under these environmental conditions is likely to be due to a greater increase in venous pooling with a consequent smaller venous return and a reduced stroke volume.

EVAPORATIVE MASS LOSS

The male children had a significantly lower relative evaporative weight loss compared to the male adults when exercising in the two hot climates.

The evaporative heat loss index which standardised the evaporative weight loss for differences in heat production between the groups and individuals also demonstrated that the children evaporated less sweat than the adults in hot wet and hot dry environmental conditions.

The evaporative heat loss index analysed for the total group also indicated that there were significant status and sex effects. The children sweated relatively less than the adults and the females sweated relatively less than the males.

Since both the children and the adults were in thermoequilibrium the lesser sweat rates of the children indicated that they do not need to sweat as much as the adults because they lose heat convectively at a faster rate. It can also be inferred that the children probably had a reduced wettedness and consequently an increased sweating efficiency, which further decreased the children's need to sweat in comparison to the adults.

MEAN SKIN TEMPERATURE

There were no significant differences for mean skin temperature measured by thermistor probes taped to the skin between the children and adults or between the sexes.

CORE TEMPERATURE

On average the children had an initial 0.4 to 0.5°C higher core temperature than the adults measured in the ear canal in the two hot climates. This difference was maintained over the 30 minutes of the exercise test.

In this study the localized cooling effect of air at T_a=22°C and V = 4 m.sec^{-1} produced a final T_{ec} 0.7°C below that found in the T_a = 31°C environment. This was considered to be a major localized effect on the measurement of the T_{ec} which made it a poor measure of core temperature in these neutral environmental conditions with moderate air velocities.

The difference in T_{ec} between the adult and children groups was not affected when SA/mass was used as a covariate.

The female children appeared to be more affected by exercise in hot wet and hot dry environmental conditions than the male children. Their self reduction of exercising work rates in the heat was probably a result of their lower fitness capabilities as measured by VO_2 maximum and a lower motivation to push themselves in uncomfortably hot conditions.

CHILDREN AND ADULTS EXERCISING AT A CONSTANT METABOLISM IN HOT WET ENVIRONMENTAL CONDITIONS WITH RADIANT HEAT.

The following similarities and differences were observed between children and adults while exercising at a constant metabolism in hot wet environmental conditions with exposure to radiant heat.

HEAT PRODUCTION

The children had an aerobic fitness level which was equal to the adults but they were exercising at a 4% lower percentage of VO_2 maximum. The children's 6% lower metabolic efficiency compensated for their lower exercise intensity and enabled both groups to produce an equal metabolic heat stress of 7.3 $W.kg^{-1}$.

SWEAT RATE

The relative sweat rates of the children were practically the same as the adults in both the low and high radiant heat conditions. The application of radiant heat to the back and the lateral aspect of the left upper arm (approximately 20% of the skin's surface) probably resulted in the children absorbing radiant heat at a faster rate than the adults. This likely increased radiant heat gain appears to have neutralized the greater convective heat loss of the children.

The sweat heat loss index which standardised for different quantities of heat production also supports the above findings on relative sweat rates with both the children and adults producing closely similar sweat heat loss indices in the low and high radiant conditions. The SHLI was used instead of the EHLI used in the first experiment because the radiant heat produced large beads of sweat on the backs of both children and adults and sweat dripped on the floor. It was consequently considered inappropriate to assume that the majority of sweat was evaporated.

CORE TEMPERATURE

The ear canal temperature of the children's group was 0.3°C higher than the adult group at the beginning of the exercise test. This difference between the adults and children remained relatively the same for the duration of the 40 minute exercise tests and was similar to the 0.4-0.5°C difference between the adults and children in the first experiment in the hot wet conditions without radiant heat.

When SA/mass was covaried against the core temperature the mean difference between the children and adults was removed. In conclusion it can be said that the small differences in T_{ec} between children and adults was predominantly related to their body size.

SKIN TEMPERATURE (T_{SNR})

In general it can be claimed that the children had a higher T_{snr} than the adults when the skin temperature was measured by a surface infrared thermometer and both groups were exercising in hot wet environmental conditions. This higher skin temperature increased the skin to air temperature gradient and consequently increased the rate of convective heat loss of the children in comparison to the adults.

SKIN TEMPERATURE (T_{SER})

The effect of the radiant heat flux was similar for the adults and the children in that the initial 1.7°C difference in T_{ser} measured before the radiant heat was applied was maintained under both low and high radiant heat fluxes. Both groups were affected by the same amount in the high radiant condition and increased their T_{ser} by 3.0°C compared to the low radiant condition.

The higher T_{ser} of the children also increased their skin to air temperature gradient and consequently increased their rate of convective heat loss in comparison to skin not exposed to radiant heat. The potential for evaporative heat loss was also increased with the higher T_{ser} increasing the water vapour pressure difference between the skin and the air.

Both groups increased their sweat rates by the same proportion when they exercised in the low radiant heat condition and then in the high radiant condition. This indicated that the children's increased radiant heat load compared to the adults had been matched by an increased rate of convective heat loss.

It is apparent that the greater convective heat loss of the children in comparison to the adults occurs at the areas of the skin exposed and those not exposed to radiant heat.

HEART RATE

The children exercised at a 6-7% higher percentage of heart rate maximum than the adults when both groups were performing at a similar %VO_2 maximum in the hot wet environmental conditions with radiant heat. This difference in %heart rate maximum would have been larger if the children's 4% lower %VO_2 maximum was taken into consideration. This result along with the similar result in part A of the study further reinforces the contention that children have a relatively greater volume of blood in their skin as a proportion of their total blood volume compared to adults.

There was a similar cardiovascular drift over the 30 minutes of the constant metabolism thermoregulation exercise tests between adults (5%) and children (7%). There was also a 4% higher cardiovascular drift in the high radiant condition compared to the low radiant condition averaged over both groups. This implies that the larger radiant heat load may require an increase in the skin blood flow so that the additional radiant heat can be dissipated from the skin. A larger skin blood flow could then be linked with a smaller venous return and a smaller stroke volume. This would produce a higher heart rate so that the constant work rate could be maintained.

The heart rate index in general supported the percentage of heart rate maximum data with the children having a higher HRI than the adults in both the low and high radiant conditions. However, the HRI had a large variability and since some of the trends do not reach significance more credence was placed on the more precise measurement; percentage of heart rate maximum. The calculation of the HRI could be improved in the future by averaging heart rates and oxygen uptake over 2-3 minutes and then calculating the index.

SURFACE AREA/MASS RATIO

The use of the SA/mass ratio as a covariate eliminated the differences between adults and children on the percentage of heart rate maximum, core temperature and the skin temperatures not exposed to radiant heat, but had no effect on the difference between children and adults for T_{scr}.

CHILDREN AND ADULTS EXERCISING AT AN INCREASING LEVEL OF METABOLISM IN HOT WET ENVIRONMENTAL CONDITIONS WITH RADIANT HEAT.

The following similarities and differences were observed between children and adults while exercising at increasing levels of metabolism in hot wet environmental conditions with exposure to radiant heat.

METABOLIC EFFICIENCY

The children were between 5-7% less efficient than the adults when they exercised at the three work levels of the increasing metabolism test. There were no main effects for differences on the percentage of VO_2 maximum between the groups; the average $\%VO_2$ maximum for both groups being 38% at the first work level, 49% at the second work level and 64% at the third work level. The lower efficiency of the children infers that they will produce more metabolic heat per kg of body mass compared to the adults at easy, moderate and heavy work levels as long as both groups have similar aerobic fitness levels.

HEAT PRODUCTION

In the low radiant condition the children and adults produced similar amounts of metabolic heat. However, in the high radiant condition the children produced significantly more metabolic heat per kg of body weight than the adults. This relatively larger variability in VO_2 of the children compared to the adults was most likely a result of the children varying their cycling rates as the resistances were maintained at the same level in both radiant heat conditions. Once again these results support the contention that children are a lot more variable in their application of constant work rates than adults.

SWEAT RATE

In general there were similar relative heat productions and similar relative sweat rates between the two groups. However, when compared to the adult group there was a trend for the children to have a greater relative heat production (average 10.8% higher) and a higher relative sweat rate (8.2% higher) in the high radiant heat condition.

There were no significant differences on the SHLI between children and adults. The high radiant heat condition averaged over both groups had a 13% higher SHLI than the low radiant heat condition.

In general as the two groups were matching their relative metabolic heat loads and relative sweat rates, these results indicate that while the children were absorbing a greater radiant heat load than the adults they were also convectively losing heat at a faster rate.

CORE TEMPERATURE

The children had a 0.4°C higher core temperature than the adults throughout the 30 minutes of the increasing metabolism exercise test. This indicated that the children and adults both increased their core temperature to the same extent when their exercise intensity was increased by similar percentages of VO_2 maximum.

SKIN TEMPERATURES

The children had a 0.7°C higher T_{sur} than the adults. There was no effect for the level of radiant heat. The higher skin temperatures of the children plus the children's theoretically larger h_c enables them to lose significantly more heat convectively than adults on approximately 80% of the skin's surface which was not exposed to radiant heat.

The children and adults increased their T_{ser} by a similar amount between low and high levels of radiant heat, but the children also recorded a 1-2°C higher mean T_{ser} than the adults; most likely due to their higher initial temperature of the skin before being exposed to radiant heat.

HEART RATE

The children were between 6-9% higher on the percentage of heart rate maximum compared to the adults throughout the 30 minutes of the increasing metabolism exercise tests. This difference in %heart rate maximum can be expected to be maintained when the intensities of exercise are increased to even higher levels than the 64% VO_2 maximum reached in this study. However the children will experience cardiovascular limitations before the adults because they have a smaller heart rate reserve.

The heart rate index was found to be unsuitable for the increasing metabolism experiment because of the large variability experienced for this index and also because there was an unequal proportional response between the percentage of heart rate maximum and the percentage of VO_2 maximum at the different intensities of exercise.

SURFACE AREA/MASS RATIO

The differences between children and adults in the first 10 minutes of the increasing metabolism test on T_{msr}, T_{ser}, T_c and the percentage of heart rate maximum was removed by using SA/mass as a covariate. This indicated that the children's size was a likely reason for the differences observed in thermoregulatory responses between adults and children exercising in hot humid environmental conditions with radiant heat.

3) CONCLUSIONS

The thermoregulatory and physiological adjustments to exercise in hot environmental conditions (T_a = 30-36°C) differs in several ways between the prepubertal child and the young adult. The following conclusions were drawn from this study.

i) In general the children had a 6-7% lower metabolic efficiency than the adults exercising on a cycle ergometer at easy, moderate and hard work rates. This means that the children will have a greater relative heat production than the adults when they are exercising at a similar percentage of VO_2 maximum and when both groups have equal aerobic fitness levels.

ii) The children appeared to be more variable than the adults in their application of a constant work rate; both between different thermoregulatory exercise tests and over the duration of these tests.

iii) The female children's reduction of work rates in the heat in comparison to exercise in neutral environmental conditions indicated that they appeared to be more affected by exercise in hot conditions than the male children. This result was most likely due to the female children having lower aerobic fitness levels and showing a lack of motivation to work hard in the heat.

iv) The children maintained a higher percentage of heart rate maximum than the adults when both groups were exercising at 50% of VO_2 maximum in neutral and hot wet environmental conditions. In the neutral conditions (T_a = 22°C) the children exercised at a 10% higher percentage of heart rate maximum than the adults. In hot wet environmental conditions (T_a = 31°C, RH = approximately 70%) without radiant heat both the male children and the male adults increased their percentage of heart rate maximum by 6 to 7% above that produced in the neutral conditions.

v) In hot dry environmental conditions (T_a = 35°C, RH = approximately 35%) without radiant heat the male children increased their percentage of heart rate maximum to 13% above that produced in the neutral conditions. This increase in the %heart rate maximum was significantly more than the 7% increase experienced by the male adults. The higher percentage of heart rate maximum recorded by the children under these conditions was likely to be due to a greater increase in venous pooling with a consequent smaller venous return and a reduced stroke volume.

vi) The male children had a lower relative evaporative weight loss than the male adults when they were both exercising at 50% VO_2 maximum in hot environmental conditions with a similar relative metabolic heat load. It was apparent that the children's larger surface area/mass enabled them to lose heat convectively at a faster rate than the adults and consequently thermoequilibrium was maintained with a lower relative evaporative heat loss.

vii) The children exercised with slightly higher mean skin temperatures than the adults in hot wet environmental conditions. While there were no major differences between the children and adults for mean T_s measured by thermistors taped to the skin, infrared surface thermometry established that the children generally recorded higher mean skin temperatures than the adults when they were both exercising in hot wet environmental conditions. The children recorded skin temperatures when the skin was not exposed to radiant heat that were between 0.7-1.7°C higher than those recorded on adults. The children also recorded skin temperatures when the skin was exposed to radiant heat which were between 1.0-2.0°C higher than those recorded for adults. The higher skin temperatures of the children increased their skin to air temperature gradient and enabled them to lose heat convectively at a faster rate than the adults.

viii) The temperature in the ear canal which represented the core temperature in this study averaged between 0.3-0.5°C higher in the children compared to the adults when both groups were exercising in hot conditions both with and without radiant heat. This did not appear to place the children at a thermoregulatory disadvantage when they were exercising at a constant metabolism as they reached thermoequilibrium early in the 30 or 40 minute thermoregulatory exercise tests.

ix) The children exercising in hot wet environmental conditions with approximately 20% of the skin's surface exposed to radiant heat produced similar relative sweat rates to the adults. Since children apparently lose heat convectively faster than adults in these conditions, it can be hypothesized that the increased radiant heat load of this group was neutralized as both groups had similar relative sweat rates and heat productions. This hypothesis is subject to the possibility of unequal sweat efficiencies occuring between adults and children.

x) There was a 4% higher cardiovascular drift during the 40 minutes of exercise in the hot wet environmental conditions with high levels of radiant heat compared to exercise in the same conditions with low levels of radiant heat. This result was similar for the children and adult groups. It can be hypothesized that this greater cardiovascular drift was a result of the efforts of the cardiovascular system to dissipate the extra heat load.

xi) The children recorded a 6-7% higher percentage of heart rate maximum compared to the adults when both groups were exercising at close to 50% of VO_2 maximum in hot wet environmental conditions with radiant heat. Since previous experiments at 50% VO_2 maximum had placed the children's %heart rate maximum 10% higher than the adults in both neutral and hot wet conditions without radiant heat, this result indicated that the children and adults were similarly affected by exercise in hot wet conditions with radiant heat. A similar cardiovascular drift experienced by both groups over the 30 minutes of exercise in hot wet conditions with radiant heat also indicated that they were both affected to the same extent in these conditions.

xii) In the increasing metabolism exercise test in hot wet environmental conditions with radiant heat the children and adults had similar relative sweat rates and similar relative heat productions. The children also maintained a 6 to 7% higher percentage of heart rate maximum compared to the adults at the three increasing work rates. These results also indicated that the children and adults responded in a similar manner to exercise in hot wet environmental conditions with exposure to radiant heat.

xiii) The increasing metabolism exercise test increased the T_{ec} of the children and adults to the same extent. While the children will have higher core temperatures than adults when exercising at similar percentages of VO_2 maximum they will also reach limiting heart rates sooner than adults. If 90% of heart rate maximum is considered to be the upper limit of aerobic exercise, children will reach this level at a 10% lower percentage of VO_2 maximum than adults. Consequently core temperatures are likely to increase to similar levels as those recorded by adults with close to maximal exertion exercise in hot wet environmental conditions with radiant heat.

xiv) The SA/mass ratio used as a covariate eliminated the majority of differences between adults and children on the dependent variables in each of the three experiments performed in this study. It was concluded that the physical size difference between children and adults was the major reason for the thermoregulation differences between these groups.

4) IMPLICATIONS OF THE CONCLUSIONS

i) The lower metabolic efficiency and the lower relative exercise intensity of prepubertal children resulted in a lower relative H_p compared to adults. However, when children are required to exercise at the same absolute work intensity as adults they will increase their relative heat production to a higher level than the adults. Also, when children are exercising at the same relative intensity as adults and have an equal or higher VO_2 maximum they will have a higher relative heat production than the adults.

ii) Prepubertal children exercising indoors in a hot wet climate will generally thermoregulate as well as adults. The precautions taken for adults exercising in these conditions are also appropriate for children.

iii) Prepubertal children exercising in a hot wet climate with exposure to radiant heat will also generally thermoregulate as well as adults. The precautions taken for adults in these conditions are also appropriate for children.

iv) There is a tendency for children to have a larger cardiovascular drift than adults when they are exercising indoors in a hot dry climate. This indicates that children will tire faster and terminate exercise sooner due to their more rapidly increasing heart rates.

v) Children sweat in relation to their heat production in a similar way to adults. They therefore need to replace fluids in proportion to their sweat loss which is closely related to their body size.

vi) Children exercising exhaustively in hot wet conditions will most likely be limited by their cardiovascular system. Adults, however can be limited by both their thermoregulatory and cardiovascular systems as evidenced by the numerous cases of heat exhaustion produced in fun runs like the Sydney City to Surf (Richards, 1986).

5) RECOMMENDATIONS FOR FURTHER STUDY

i) Further research on children exercising in a hot dry climate with radiant heat is needed to evaluate the full extent of the thermoregulatory limitations of children exercising in these conditions.

ii) Research conducted in the field is needed to ascertain if the findings produced in the climate chamber are confirmed when children play sport in hot indoor and hot outdoor environments.

iii) Research needs to be conducted on children who live in hot wet and hot dry environments to examine their level of acclimatization in comparison to adults.

iv) Finally there needs to be a comparison of the thermoregulatory responses of children playing interval type games in hot conditions with the responses of children performing continuous effort activities in the same hot conditions.

REFERENCES

Adams, K. Human body temperature is inversely correlated with body mass. *European Journal of Applied Physiology* 58:471-475, 1989.

American Academy of Pediatrics. Committee on Sports Medicine. Climatic heat stress and the exercising child. *Pediatrics* 69(6):808-809, 1982.

American Academy of Pediatrics. Climatic heat stress and the exercising child. *The Physician and Sports Medicine* 11(8):155-159, August, 1983.

Araki, T., Tsujita, J., Matsushita, K. and Hori, S. Thermoregulatory responses of prepubertal boys to heat and cold in relation to physical training. *Journal of Human Ergology* 9:69-80, 1980.

Armstrong, L. Prepubescent response to extreme environments. *National Strength and Conditioning Association Journal* 11(5):67,1989.

Asano, K. and Hirakoba, K. Respiratory and Circulatory Adaptation during prolonged exercise in 10-12 year children and adults. In J.Ilmarinen and I.Valimaki (Editors) *Children in sport.* Springer-Verlag, 1984.

Asmussen, E. Development patterns in physical performance capacity. In L.A.Larson (Editor) *Fitness, health and work capacity.* Macmillan, 1974.

Austin, D.M. and Lansing, M.W. Body size and heat tolerance: A computer simulation. *Human Biology* 58(2):153-169, April,1986.

Australian Sports Medicine Federation Position Statement. *Children in Sport. Endurance Running.*

Bar-or, O. Climate and the exercising child. A review. *International Journal of Sports Medicine* 1:53-65,1980.

Bailey, D. Sport and the child: physiological considerations. In R. Magill M. Ash F. Smoll (Editors) *Children in sport.* Human Kinetics, 1982.

Bar-or, O. *Pediatric sports medicine for the practitioner.* Springer-Verlag, 1983.

Bar-or, O. The child athlete and thermoregulation. In P.V. Komi, R.C. Nelson, C. Morehouse (Editors) *Exercise and sport biology. International symposium on sport biology.* Human Kinetics, 1982.

Bar-or, O. The growth and development of children's physiologic and perceptual responses to exercise. In J. Ilmarinen and I. Valimaki (Editors) *Children and Sport.* Springer-Verlag, 1984.

Bar-or, O., Shepard, R. and Allen, C. Cardiac output of 10 and 13 year old boys and girls during submaximal exercise. *Journal of Applied Physiology* 30(2):219-223, 1971.

Bar-or, O., Dotan, R., InBar, O., Rotshtein, A. and Zonder, H. Voluntary hypohydration in 10-12 year old boys. *Journal of Applied Physiology* 48(1):104-108, 1980.

Bar-or, O. and Inbar, O. Relationship between perceptual and physiological changes during heat acclimatization in 8-10 year old boys. In R. Shepard and H. la Vallee (editors) *Frontiers of activity and child health*. Editions du Pelican, 1977.

Bar-or, O. Trainability of the prepubescent child. *The Physician and Sports Medicine* 17(5):65-82, May 1989.

Bar-or, O., Children and physical performance in warm and cold environments. In R.Boileau (Editor) *Advances in pediatric sport sciences. Volume one. Biological issues*. Human Kinetics, 1984.

Benzinger, T.H. The human thermostat. *Scientific American* Reprint Jan., 1961.

Berg, K., Eriksson, B., Nelson, R. and Morehouse, C. (Editors) *Children and exercise IX. International series on sport sciences*. Volume 10. University Park Press, 1980.

Berger, X. and Grivel, F. Mean skin temperature in warm humid climates. *European Journal of Applied Physiology* 59:284-289, 1989.

Beyer, C.B. Heat stress and the young athlete. *Postgraduate Medicine* 76(1):109-112. July, 1984.

Binkhorst, R., Kemper, H. and Saris, W. (Editors) *Children and exercise XI. International series on sport sciences*. Volume 15. Human Kinetics, 1985.

Blum, H.F. The solar heat load: its relationship to total heat loss and its relative importance in the design of clothing. *Journal of Clinical Investigation* 24:712-721, 1945.

Borms, J. The child and exercise: An overview. *Journal of Sports Sciences* 4:3-20,1986.

Borut, A., Dmi'el, R. and Shkolnik, A. Heat balance of resting and walking goats. Comparison of climatic chamber and exposure in the desert. *Physiological Zoology* 52:102-112, 1979.

Brengelmann, G.L. Circulatory Adjustments to exercise and heat stress. *Annual Review of Physiology* 45:191-212,1983.

Brotherhood, J.R. The practical assessment of heat stress. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment*. Exerpta Medica, 1987.

Brown, S.L. and Banister, E.W. Thermoregulation during prolonged actual and laboratory simulated bicycling. *European Journal of Applied Physiology* 54: 125-130, 1985.

Buettner, K. Effects of extreme heat and cold on human skin. Analysis of temperature changes caused by different kinds of heat application. *Journal of Applied Physiology* 3(12):691-702, June 1951.

Bureau of Meteorology. *Climatic atlas of Australia*. 1979.

Cabanac, M. and Caputa, M. Open Loop increase in trunk temperature produced by face cooling in working humans. *Journal of Physiology* 289:163-174,1979.

Candas, V., Libert, J., Hoeft, A. and Vogt, J. The required wettedness and the sweat rate. In Y. Houdas and J. Guiev (Editors) *New trends in thermal physiology*. Masson, 1978.

Candas, V., Libert, J., Sagot, J. and Vogt, J. Thermophysiological responses to humid heat: Sex differences. *Journal of Physiology* 78:240-242,1982.

Chatonnet, J. Review. Some general characteristics of temperature regulation. *Journal ofThermal Biology* 8:33-36,1983.

Consolazio, C., Johnson, R., Pecora, L. *Physiological measurement of metabolic function in man.* McGraw Hill, 1963.

Cooper, D.M., Weiler-Ravell, D., Whipp, B. and Wasserman, K. Aerobic parameters of exercise as a function of body size during growth in children. *Journal of Applied Physiology* 56(3):628-634, 1984.

Davies, C.T.M. Thermoregulation during exercise in relation to sex and age. *European Journal of Applied Physiology* 42:71-79,1979.

Davies, C.T.M. Thermal responses to exercise in children. *Ergonomics* 24(1):55-61,1981.

Davies, M. The thermal stress of prolonged exercise in children. In *Children and exercise*. Cumberland College of Health Sciences. 1982.

Davies, M. Temperature regulation in adults and young children during severe exercise. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment.* Exerpta Medica, 1987.

Dawson, N., de Freitas, C., Mackey, W. and Young, A. The stressful microclimate created by massed fun-runners. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment.* Exerpta Medica, 1987.

Dawson, B. and Pyke, F. The effects of heat stress on anaerobic threshold. *The Australian Journal of Science and Medicine in Sport* 16(1):3-9, 1984.

de Knecht, S., Saris, W., Daniels, O., Elvers, J. and de Boo, T. Echocardiographic study of the left ventricle in sedentary and active boys aged 8-9 years. In J. Ilmarinen and I. Valimaki (Editors) *Children in sport.* Springer-Verlag,1984.

Dick, F.W. *Sports training principles.* Lepus Books,1980.

Dill, D., Hall, F. and Van Beaumont, W. Sweat chloride concentration. Sweat rate, metabolic rate, skin temperature and age. *Journal of Applied Physiology* 21(1):99-106, 1966.

Docherty, D.,Eckerson, J., Hayward, J., Physique and thermoregulation in prepubertal males during exercise in a warm humid environment. *American Journal of Physical Anthropology* 70(1):19-24,1986.

Drinkwater, B.L., Kupprat, I., Denton, J., Crist, J. and Horvath, S.M. Responses of pre-pubertal girls and college women to work in heat. *Journal of Applied Physiology* 43(6):1046-1053, 1977.

Drinkwater, B.L. and Horvath, S.M. Heat tolerance and aging. *Medicine and Science in Sport* 11(1):49-55, 1979.

Edwards, R., Belyauin, A., Harrison, M. Core temperature measurement in man. *Aviation Space Environment and Medicine* 49(11):1289-1294, 1978.

Egger, G., and Champion, N. *The new fitness leaders handbook.* Kangaroo Press, 1986.

Ellis, H. Metabolism and solar radiation in dark and white herons in hot climates. *Physiological Zoology* 53:3358-3372,1980.

Epstein, Y., Shapiro, Y. and Brill, S. Role of surface area to mass ratio and work efficiency in heat intolerance. *Journal of Physiology* 54(3):831-838, 1983.

Folinsbee, L., Wagner, J., Borgia, J., Drinkwater, B., Jeffrey, A. and Bedi, J.(Editors) *Environmental stress. Individual human adaptations.* Academic Press, 1978.

Fortney, S.M. and Vroman, N.B. Exercise, performance and temperature control. Temperature regulation during exercise and implications for sports performance and training. *Sports Medicine* 2:8-20, 1985.

Fox, E.L. *Sports physiology* Saunders, 1979.

Frye, A.J. and Kamon, E. Sweating efficiency in acclimated men and women exercising in humid and dry heat. *Journal of Applied Physiology* 54:972-77, 1983.

Fujishima, K. Thermoregulatory responses during exercise and a hot water immersion and the affective responses to peripheral thermal stimuli. *International Journal of Biometeorology* 30(1):1-9,1986.

Gavhed, D. and Ingvar, H. Thermoregulatory responses of firemen to exercise in the heat. *European Journal of Applied Physiology* 59:115-122, 1989.

Gauthier, R., Massicotte, D. and Weihrer, S. Canadian norms of predicted oxygen uptake of children aged 6-17. *Journal of Human Movement Studies* 15:129-140, 1988.

Gisolfi, C. and Wenger, C. Temperature regulation during exercise. Old concepts, new ideas. In R.Terjung (Editor) *Exercise and Sport Sciences Reviews* Volume 12, Collamore Press, 1984.

Godfrey, S., Davies, C.T.M., Wozniak, E. and Barnes, C.A. Cardiorespiratory response to exercise in normal children. *Clinical Science* 40:419-431,1971.

Godfrey, S. The response of normal children to exercise. In *Exercise testing in children. Application in health and disease.* Saunders, 1974.

Goldman, R. Prediction of human heat tolerance. In L.Folinsbee, J. Wagner, J. Borgia, B. Drinkwater, J. Gliner and J.Bedi,(Editors) *Environmental stress. Individual human adaptations.* Academic Press, 1978.

Goss, F., Herbert, W. and Kelso. W. A comparison of mean skin temperatures during prolonged cycle exercise, *Research Quarterly for Exercise and Sport* 60(3):292-296, 1989.

Goss, F. *Thermoregulation during prolonged exercise.* Thesis, Doctor of Philosophy. Polytechnic University, Virginia 1983.

Graichen, H., Rascati, R. and Gonsalez, R. Automatic dew-point temperature sensor. *Journal of Applied Physiology* 52(6):1658-1660,1982.

Gregory, W. *Thermoregulatory boundaries to exercise in hot, humid environments.* Thesis, Doctor of Philosophy. Graduate College of Texas A & M University. December 1979.

Greehaff, P. and Clough, P. Predictors of sweat loss in man during prolonged exercise. *European Journal of Applied Physiology* 58:348-352, 1989.

Grucza, R. The model of human thermoregulatory system for positive heat loads. *Acta Physiologica Polica* 33(4):305-315,1982.

Grucza, R. Body heat balance in man subjected to endogenous and exogenous heat load. *European Journal of Applied Physiology* 51:419-433,1983.

Gullestad, R. Temperature regulation in children during exercise. *Acta Pediatrica Scandinavica* 64:257-263, 1975.

Gupta, J., Swamy, Y.,Pichan, G. and Dimri, G. Physiological responses during continuous work in hot dry and hot humid environments in Indians. *International Journal of Biometeorology* 28(2):137-146, 1984.

Gupta, J.,Swamy, Y.,Drimi, G. and Pichan, G. Physiological responses during work in hot humid environments. *Indian Journal of Physiology and Pharmacology* 25(4):339-347, Oct-Dec 1981.

Hales, J. Proposed mechanisms underlying heat stress. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment.* Exerpta Medica, 1987.

Hales, J. and Richards,D.(Editors) *Heat stress.Physical exertion and environment.* Exerpta Medica, 1987.

Hardy, J.D. Method for the rapid measurement of skin temperature during exposure to intense thermal radiation. *Journal of Applied Physiology* 5(9):559-566,1953.

Haycock, G.B., Chwartz, G. and Wistosky, D. Geometric method for measuring body surface area. A height and weight formula validated in infants, children and adults. *The Journal of Pediatrics* 93(1):62-6, 1978.

Haymes, E. Physiological responses of female athletes to heat stress. A review. *The Physician and Sports Medicine* 12:45-59,1984.

Haymes, E.M., McCormick, R.M. and Buskirk, E. Heat tolerance of exercising lean and obese prepubertal boys. *Journal of Applied Physiology* 39(3):457-461,1975.

Haymes, E., Buskirk, E., Hodgson, J., Lungegren, H. and Nicholas, W. Heat tolerance of exercising lean and heavy prepubertal girls. *Journal of Applied Physiology* 36:566-571, 1974.

Hayward, J.S., Eckerson, J. and Dawson, B. Effect of mesomorphy on hyperthermia during exercise in a warm humid environment. *American Journal of Physical Anthropology* 70(1): 11-17, 1986.

Heising, M. and Werner, J. Differential heating of trunk and extremities. Effects on thermoregulation mechanisms. *European Journal of Applied Physiology* 54:79-83, 1985.

Hirata, K., Nagasaka, T., Numomura, T., Hirai, A. and Hirashita, M. Effects of facial fanning on local exercise performance and thermoregulatory responses during hyperthermia. *European Journal of Applied Physiology* 56:43-48,1987.

Hirata, K., Nagasaka, T., Hirai, A., Hirashita, M. and Takahata, T. Cutaneous vascular tone during heat load modified by exercise intensity. *Journal of Thermal Biology* 9(1/2):117-120, 1984.

Hori, S. and Ihzuka, H. Correlation between heat tolerance during exercise and maximum aerobic capacity. *Journal of Human Ergology* 8(2):109-115,1979.

Houdas, Y. and Guieu, J.(Editors) *New trends in thermal physiology*. Masson,1978.

Iampietro, P. Use of skin temperature to predict tolerance to thermal environments. *Aerospace Medicine* 42(4):396-399,1971.

Inbar, O., Dotan, R., Bar-or, O. and Gutin,B. Passive versus active exposure to dry heat as methods of heat acclimatization in young children. In R.Binkhorst, H. Kemper and W. Saris (Editors) *Children and exercise XI*. Human Kinetics, 1985.

Inbar, O. and Bar-or, O. Anaerobic characteristics in male children and adolescents, *Medicine and Science in Sports and Exercise* 18(3):264-269,1986.

Inbar, O., Bar-or, O., Dotan, R. and Gutin, B. Conditioning versus exercise in heat as methods for acclimatizing 8-10 year old boys to dry heat. *Journal of Applied Physiology* 50(2):406-411, 1981.

Inbar, O. *Acclimatization to dry and hot environments in young adults and children 8-10 years old*. Thesis, Doctor of Philosophy, Columbia University, 1978.

Ilmarinen, J. and Valimaki, I. *Children and sport*. Springer-Verlag, 1984.

Jessen, C. Hyperthermia and its effects on exercise performance. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment*. Exerpta Medica, 1987.

Jessen, C. Thermoregulatory mechanisms in severe heat stress and exercise. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment*. Exerpta Medica, 1987.

Johnson, K. and Hales, J. An Introductory analysis of competition between thermoregulation and other homeostatic systems. In J. Hales (editor) *Thermal physiology*. Raven Press, 1984.

Johnson, J. Central and peripheral adjustments to long term exercise in humans. *Canadian Journal of Sport Science* 12: Suppl 1:84S-88S,1987.

Jones, P., Wilkinson, S. and Davies, P. A revision of body surface area estimations. *European Journal of Applied Physiology* 53:376-379, 1985.

Kamon, E., Avellini, B. and Krajewski, J. Physiological and biophysical limits to long term work in the heat for clothed men and women. *Journal of Applied Physiology* 44(6):918-925, 1978.

Kamon, E., Benson, J. and Soto, K. Scheduling work and rest for the hot ambient conditions with radiant heat source. *Ergonomics* 26(2):181-192, 1983.

Katch, F. I., and Katch, V.L. The body composition profile; techniques of measurement and applications. *Clinical Sports Medicine* 3:31, 1984.

Kemper, H., Verschuur, R. and de Mey, L. Longitudinal changes of aerobic fitness in youth 12 to 23. *Pediatric Exercise Science* 1:257-270, 1989.

Kenny, W.L. Physiological correlates of heat intolerance. *Sports Medicine* 2:279-286, 1985.

Kenny, W. A review of comparative responses of men and women to heat stress. *Environmental Research* 37(1):1-11, June 1985.

Kerslake, D.M. *The stress of hot environments.* Cambridge University Press, 1972.

Khogali, M. and Mustafa, M. Physiology of heat stroke: a review. In J. Hales (Editor) *Thermal physiology.* Raven Press, 1984.

Kielblock, A. A critical review of parameters of heat tolerance with specific reference to indices of heat stress. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment.* Exerpta Medica, 1987.

Kivett, L. *Physiological responses to exercise in a hot dry versus a hot humid environment.* Masters Thesis, Western Illinois University, August 1981.

Klausen, K., Rasmussen, B., Glensgaard, L. and Jensen, O. Work efficiency of children during submaximal bicycle exercise. In R. Binkhorst, H. Kemper and W. Saris (Editors) *Children and exercise XI.* Human Kinetics, 1985.

Koch, G. Muscle blood flow in prepubertal boys. *Medicine Sport* 11:39-46,1978.

Kolka, M. and Stephenson, L. Control of sweating during the human menstrual cycle. *European Journal of Applied Physiology* 58:890-895, 1989.

Kornienko, I. Energy metabolism at different periods of human individual development. *Human Physiology* 9(1):7-14, 1983.

Kornienko, A. and Gokhblit, I. Age differences of temperature regulation in children aged 5-12. *Human Physiology* 6(6):443-449, 1980.

Kraning, K., Belding, H. and Hertig, B. Use of sweating rate to predict other physiological responses to heat. *Journal of Applied Physiology* 21(1):111-117, 1966.

Krahenbuhl, G., Pangrazi, R., Stone, W., Morgan, D. and Williams, T. Fractional utilization of maximal aerobic capacity in children 6 to 8 years of age. *Pediatric Exercise Science* 1:271-277, 1989.

Kuno, Y. *Human perspiration.* Charles C. Thomas, 1956.

Larson, L. (Editor) *Fitness, health and work capacity.* Macmillan, 1974.

Lawson, D. Considerations in estimating cardiorespiratory fitness in children. *Transactions of the Menzies Foundation* Volume 5:57-61,1983.

Lawson, D., Payne, W., Naughton, G. and Lausson S. Mechanical efficiency of male children. (Abstract) *Beijing International Conference on Sports Medicine.* Chinese Association of Sports Medicine Conference. November 1985.

Libert, J., Candas, V., Sagot, J., Meyer, J., Vogt, J., and Ogawa, T. Contribution of skin thermal sensitivities of large body areas to sweating response. *Japanese Journal of Physiology* 34:75-88,1984.

Lohman, T., Slaughter, M., Boileau, J., Bunt, J. and Lussier, L. Bone mineral measurements and their relation to body density in children, youth and adults. *Human Biology* 56(4):667-679,1984.

Lohman, T., Boileau, R. and Slaughter, M. Body composition in children and youth. In Boileau (Editor) *Advances in pediatric sports science.* Human Kinetics, 1984.

Lohman, T. The use of skinfolds to estimate body fat in children and youth. *Journal of Physical Education Recreation and Dance* 58:98-102, 1987.

Lohman, T. Assessment of body composition in children. *Pediatric Exercise Science* 1:19-30, 1989.

Lowrey, G.H. *Growth and development of children.* Eighth Edition. Year Book Medical Publishers, 1986.

Ludbrook, J. Gross cardiovasular regulation in heat stress and exercise. In J.Hales and D.Richards (Editors) *Heat stress. Physical exertion and environment.* Exerpta Medica, 1987.

MacDougall, J.D., Roche, P., Bar-or, O. and Moroz, J. Maximal aerobic capacity of Canadian school children: Prediction based on age-related oxygen cost of running. *International Journal of Sports Medicine* 4:194-198,1983.

MacDougall, D.J. Reddan, W.G., Layton, C. and Dempsey, J. Effects of metabolic hyperthermia on performance during heavy prolonged exercise. *Journal of Applied Physiology* 36(5):538-544, 1974.

McCaffrey, T., McCook, R. and Wurster, R. Effect of head skin temperature on tympanic and oral temperature in man. *Journal of Applied Physiology* 39(1):114-118, July 1975.

Malina, R.M. Adolescent changes in size, build, composition and performance. *Human Biology* 46(1):117-131, 1974.

Malina, R.M. Growth of muscle tissue and muscle mass. In F. Falkner and J. Tanner (Editors) *Human growth 2. Postnatal growth.* Plenum Press, 1978.

Marcus, P. Some effects of radiant heating of the head on body temperature measurements of the ear. *Aerospace Medicine* 44(4):403-406,1973.

Marcus, P. Some effects of cooling and heating areas of the head and neck on body temperature measurement at the ear. *Aerospace Medicine* 44(4):397-402, 1973.

Martin, A., Drinkwater, D. and Clarys, J. Human body surface area: Validation of formulae based on a cadaver study. *Human Biology* 56(3):475-489, 1984.

Martin, C. Thermal adjustment of man and animals to external conditions. *Lancet* 219:673, 1930.

McIntyre, D. *Indoor climate.* Applied Science, 1980.

Mero, A., Kauhanen, H., Peltola, E. and Vuorimaa, T. Transfer from prepuberty to puberty. Effects of three years of training. *Journal of Human Movement Studies* 16:267-278, 1989.

Miller, J.O. Individual differences in physical characteristics among young boys. *The Australian Journal of Sport Medicine* 3(1):16-23, 1989.

Miller, G. and Martin, H. Effect of ambient temperatures between 21°C and 35°C on the responses to progressive submaximal exercise in partially acclimated man. *Ergonomics* 18(5):539-546, 1975.

Morimoto, T., Slabochova, Z., Naman, R. and Sargent II, F. Sex differences in physiological reactions to thermal stress. *Journal of Applied Physiology* 22(3):526-532, 1967.

Nadel, E. Recent advances in temperature regulation during exercise in humans. *Federation Proceedings* 44:2286-2292, 1985.

Nadel, E. Prolonged exercise at high and low ambient temperatures. *Canadian Journal of Sport Sciences.* 12: Supplement 1:140S-142S, 1987.

Nadel, E. Mack, G., Nose, H. and Tripathi, A. Tolerance to severe heat and exercise: Peripheral vascular responses to body fluid changes. In J. Hales and D. Richards (Editors) *Heat stress.Physical exertion and environment.* Exerpta Medica, 1987.

Nadel, E., Cafarelli, E., Roberts, M. and Wenger, C. Circulation controls during heavy exercise in the heat. In Y. Houdas and J. Guieu (Editors) *New trends in thermal physiology.* Masson,1978.

Nadel, E.R. Factors affecting the regulation of body temperature during exercise. *Journal of Thermal Biology* 8:165-169, 1983.

Nadel, E., Mitchell, J., Saltin, B. and Stolwijk, J. Peripheral modifications to the central drive for sweating. *Journal of Applied Physiology* 31(6):828-833, December 1971.

Nadel, E., Bullard, R. and Stolwilk, J. Importance of skin temperature in the regulation of sweating. *Journal of Applied Physiology* 31(1):80-87, July 1971.

Nadel, E. Thermal regulation and exercises. In Y. Houdas and J. Guieu (Editors) *New trends in thermal physiology.* Masson,1978.

Naughton, G., Payne, W. and Lawson, D. A comparison of the movement eficiency of 11-year-old male and female children. (Abstract) Australian Sports Medicine Federation Conference. Ballarat 1986.

Nielson, B.M., Rowell, L., Bonde-Peterson, F. Caridiovascular responses to heat stress and blood volume displacements during exercise in man. *European Journal of Applied Physiology* 52:370-374,1984.

Nielson, B., Kassow, K. and Aschengreen, F. Heat balance during exercise in the sun. *European Journal of Applied Physiology* 58:189-196, 1988.

Nielson, B., Sjogaard, G. and Bonde-Peterson, F. Cardiovascular, hormonal and body fluid changes during prolonged exercise. *European Journal of Applied Physiology* 53:63-70, 1984.

Nielson, B. The implications of endogenous versus exogenous heat loads in stress tolerance. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment.* Exerpta Medica, 1987.

Nielsen, B. Sweating sensitivity and temperature regulation during exercise. In Y. Houdas and J. Guieu (Editors) *New trends in thermal physiology.* Masson, 1978.

Nishi, Y. and Gagge, A. A psychrometric chart for graphical prediction of comfort and heat tolerance. *Ashrae Transactions* 80:115-130, 1974.

Nishi, Y. Measurement of thermal balance of man. In Cena and Clarke (Editors) *Bioengineering thermal physiology and comfort.* 1981.

O'Brien, R.G. and Kaiser, K.M. Manova method for analysing repeated measures designs: An extensive primer. *Psychological Bulletin* 97(2):316-333,1985.

Ogawa, T. Regional differences in sweating activity. In J. Hales (Editor) *Thermal Physiology.* Raven Press, 1984.

Ogawa, T. Thermal and non-thermal factors influencing sweating. *Transactions of the Menzies Foundation.* Volume 14:203-209, 1987.

Ogawa, T., Asayama, M., Sugenoya, J., Fujimatsu, H., Miyagawa, T. and Terai, Y. Temperature regulation in hot-humid environments, with special reference to the significance of hidromeiosis. *Journal of Thermal Biology* 9(1/2):121-125, 1984.

Olesen, B. How many sites are necessary to estimate a mean skin temperature. In J. Hales (Editor) *Thermal Physiology.* Raven Press, 1984.

Palgi, Y., Gutin, B., Young, J. and Alejandro, D. Physiologic and anthropometric factors underlying endurance performance in children. *International Journal of Sports Medicine* 5:67-73,1984.

Pandolf, K. and Kamon, E. Respiration responses to intermittent and prolonged exercise in a hot dry environment. *Life Sciences* 14(1):187-198, January 1974.

Paterson, D., Cunningham, D. and Bumstead, L. Recovery oxygen and blood lactic acid: Longitudinal analysis in boys aged 11-15 years. *European Journal of Applied Physiology* 55:93-99,1986.

Piekarski, C., Morfeld, P., Kampmann, B., Ilmarinen, R. and Wenzel, H. Heat stress reactions of the growing child. In J. Rutenfranz, R. Mocellin and F. Klimt (Editors) *Children and exercise XII.* Human Kinetics,1986.

Pivarnik, J. Grafner, T. and Elkins, E. Metabolic, thermoregulatory, and psychophysiological responses during arm and leg exercise. *Medicine and Science in Sport and Exercise* 20(1):1-5,1988.

Powers, S., Howley, E. and Cox, R. Blood lactate concentrations during submaximal work under differing environmental conditions. *Journal of Sports Medicine and Physical Fitness* 25:84-89, 1985.

Pyke, F. Dehydration and the athlete. The story of sweat. *Sports Coach* 7(3):15-20,1983.

Ramsay, J. and Chai, C. Inherent variability in heat stress decision rules. *Ergonomics* 26(5):495-504, 1983.

Rastogi, S., Gupta, B., Mathur, N. and Husain, T. Thermal stress and physiological strain of children exposed to hot environments in a glass bangle factory. *European Journal of Applied Physiology* 59:290-295, 1989.

Raven, R. Body's response to heat. *Sports Training, Medicine and Rehabilitation* 1:145-148,1989.

Robertshaw, D. and Finch, V. Heat loss and gain in artificial and natural environments. In J. Hales (Editor) *Thermal Physiology* Raven Press, 1984.

Roller, W. and Goldman, R. Prediction of solar heat load on man. *Journal of Applied Physiology* 24:717-721, 1968.

Richards, D. and Richards, R. Prevention and treatment of hyperthermia. In *Transactions of the Menzies Foundation* 12:27-39, 1986.

Richards, D. and Richards, C. Physiological factors predisposing to physical exhaustion. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment.* Exerpta Medica, 1987.

Richards, C. and Richards, C. Medical management of fun runs. In J. Hales and D. Richards (Editors) *Heat stress. Physical exertion and environment.* Exerpta Medica, 1987.

Robinson, S., Turrell, E. and Gerking, S. Physiologically equivalent conditions of air temperature and humidity. *Journal of Physiology* 143:21-32, 1945.

Rodgers, C. Kids and the heat. *Spotlight on Youth Sports* 12(1/2):1-3, 1989.

Ross, W.D., Bailey, D.A. and Weese, C.H. Proportionality in interpretation of longitudinal metabolic function data on boys. In R. Shepard and H. la Valle (Editors) *Frontiers of activity and child health.* Editions du Pelican, 1977.

Rowland, T. Aerobic response to endurance training in prepubescent children. A critical analysis. *Medicine and Sciences in Sports and Exercise* 17(5):493-497, 1985.

Rowland, T., Auchinachiae, J., Keenan, T. and Green, B. Physiological responses to treadmill running in adults and prepubertal males. *International Journal of Sports Medicine* 8(4):292-297, 1987.

Rowland, T. Oyxgen uptake and endurance fitness in children: a development perspective. *Pediatric Exercise Science* 1:313-328,1989.

Rowell, L. Cardiovascular adjustments to thermal stress. (chapter 27) In *Handbook of physiology.* Section 2. The cardiovascular system. Volume III, 1983.

Rowell, L. *Human circulation regulation during physical stress.* Oxford University Press, 1986.

Rutenfranz, J., Mocellin, R. and Klimt, F. (Editors) *Children and exercise XII.* Human Kinetics, 1986.

Saltin, B. and Hermansen, L. Esophageal, rectal and muscle temperature during exercise. *Journal of Applied Physiology* 21:1757-1782, 1966.

Saris, W., Noordeloos, A., Rignalda, B., Van't Hof, M. and Binkhorst, R. Reference values for aerobic power of healthy 4 to 18 year old Dutch children. In J. Rutenfranz, R. Mocellin and F. Klimt *Children and exercise XII.* Human Kinetics, 1985.

Sawka, M., Pimental, N. and Pandolf, K. Thermoregulatory responses to upper body exercise. *European Journal of Applied Physiology* 52:230-234, 1984.

Shoenfeld, Y., Udassin, R., Shapiro, Y., Ohri, A. and Sohar, E. Age and sex difference in response to short exposure to extreme dry heat. *Journal of Applied Physiology* 44(1):1-4, 1978.

Schmidt-Nielson, K. *Scaling. Why is animal size so important.* Cambridge University Press, 1984.

Senay, L. Exercise in a hostile world. *Canadian Journal of Sports Science* 12 (Suppl 1):127S-135S, 1987.

Shaffrath, J.D. and Adams, W.C. Effects of airflow and workload on cardiovascular drift and skin blood flow. *Journal of Applied Physiology* 56(5):1411-1417, 1984.

Shapiro, Y., Pandolf, K ., Avellini, B.A., Pimental, N.A. and Golman, R.F. Physiological responses of men and women to humid and dry heat. *Journal of Applied Physiology* 49(1)1-8, 1980.

Siri, W. The gross composition of the body. *Advances in Biology and Medical Physiology* 4:239-280, 1956.

Slaughter, M., Lohman, T., Boileau, R., Stillman, R., Van Loan, M., Horswill, C. and Wilmore, J. Influence of maturation on relationship of skinfolds to body density: A cross sectional study. *Human Biology* 56(4):681-689, 1984.

Smolander, J., Kolari, P., Korhonen. and Ilmarinen, R. Skin blood flow during incremental exercise in a thermoneutral and a hot dry environment. *European Journal of Applied Physiology* 56:273-280,1987.

Stanitski, C. Environmental problems of runners. *Clinics of Sports Medicine* 4(4):725-735, October 1985.

Stephenson, L., Wenger, C., O'Donovan, B. and Nadel, E. Circadian rhythm in sweating and cutaneous blood flow. *American Journal of Physiology* 246:R321-R324, 1984.

Stoll, A.and Hardy, J. Study of thermocouples as skin thermometers. *Journal of Applied Physiology* 2(10):531-543,1950.

Tanaka, M., Brisson, G., Volle, M. and Dion, M. Thermal responses during submaximal and maximal exercises in man. *Journal of Sports Medicine* 18:107-116,1978.

Tanner, J.M. *Foetus into man.* Open Books, 1978.

Telford, R., Ellis, L. and Woodman, L. Anthropometric, physiological and performance characteristics of 12 year old boys and girls. Should they co-compete. *Australian Journal of Science and Medicine in Sport* 18(4):20-24, 1986.

The Confederation of Australian Sport. The Australian Council for Health, Physical Education and recreation. The Australian Sports Medicine Federation Policy Statement. Children in sport. *ACHPER National Journal* March, 62-66, 1984.

Thoren, C. and Asano, K. Functional capacity and cardiac function in 10 year old boys and girls with high and low running performance. In J. Ilmarinen and I. Valimaki *Children and sport* Springer-Verlag, 1985.

Vroman, N., Buskirk, E. and Hodgson, J. Cardiac output and skin blood flow in lean and obese individuals during exercise in the heat. *Journal of Applied Physiology* 55(1):69-74, 1983.

Wagner, J.A., Robinson, S., Tzankoff, S . and Marino, P. Heat tolerance and acclimatization to work in the heat in relation to age. *Journal of Applied Physiology* 33(5):616-622,1972.

Wallerstrom, B., and Homer, I. Efficiency of sweat evaporation during exercise in the heat. In J. Hales (Editor) *Thermal physiology.* Raven Press, 1984.

Wells, C.L. Physiological effects of a hot environment upon physical performance. In T.K. Cureton (Editor) *Encyclopedia of physical education, fitness and sport.* Brighton,1980.

Wells, C. *Women, sport and performance. A physiological perspective.* Human Kinetics, 1985.

Wenger, C., Bailey, R., Roberts, M. and Nadel, E. Interaction of local and reflex thermal effects in control of forearm blood flow. *Journal of Applied Physiology* 58(1):251-257, 1985.

Wenzel, H.G. Heat stress upon undressed man due to different combinations of elevated environmental temperature, air humidity and metabolic heat production: A critical comparison of heat stress indices. *Journal of Human Ergology* 7: 185-206, 1978.

Wenzel, H. Evaluation of tolerance limits for humans under heat stress and the problems involved. *Scandinavian Journal of Work, Environment and Health* 15(suppl. 1): 7-14, 1989.

Wenzel, H. and Forsthoff, A. Modification of Vernon's globe thermometer and its calibration in terms of physiological strain. *Scandinavian Journal of Work, Environment and Health* 15 (suppl 1):47-51, 1989.

Werner, J. Thermoregulatory models. Recent research, current applications and future developments. *Scandinavian Journal of Work, Environment and Health* 15(Suppl 1):34-46, 1989.

Wright, G. Know your children. *Sports Coach* 7(4):7-10, 1984.

Wyndham, C., Strydom, N., Morrison, J., Williams, C., Bredell, G. and Peter, J. Fatigue of the sweat gland response. *Journal of Applied Physiology* 21(1):107-110, 1966.

Yoshizawa, S., Ishizaki, T. and Honda, H. Aerobic power and endurance running in young children. In J. Rutenfranz, R. Mocellin and F. Klimt (Editors) *Children and Exercise XII* Human Kinetics, 1986.

Zahorska-Markiewicz, B., Debowski, M., Spioch, F., Zejda, J., Sikora, A. and Markiewicz, A. Circadian variations in psychophysiological responses to heat exposure and exercise. *European Journal of Applied Physiology* 59:29-33, 1989.

Zwiren, L. Exercise prescription for children. Chapter 34 in American College of Sports Medicine. *Resource manual for guidelines for exercise testing and prescription.* Lea and Febiger, 1988.

Zwiren, L. Anaerobic and aerobic capacities of children. *Pediatric Exercise Science* 1:31-44, 1989.

APPENDIX A

PART A

MEAN DATA FOR CHILDREN AND ADULTS EXERCISING IN HOT WET AND HOT DRY ENVIRONMENTAL CONDITIONS WITHOUT RADIANT HEAT

APPENDIX A-1

AVERAGE METABOLISM AS A PERCENTAGE OF MAXIMUM OXYGEN UPTAKE

Climate	Status	Mean	Std.dev.	N	95%	confidence limits
	Males					
22°C	child	49.0	3.3	8	46.3	51.8
	adult	48.6	5.6	9	44.3	52.9
31°C	child	47.2	3.7	8	44.1	50.3
	adult	48.2	3.1	9	45.9	50.5
35°C	child	49.7	4.0	8	46.3	53.1
	adult	47.6	3.1	9	45.2	50.0
	Females					
22°C	child	47.5	5.5	7	42.4	52.5
	adult	52.9	6.0	7	47.3	58.4
31°C	child	43.4	5.1	7	38.7	48.1
	adult	53.3	4.9	7	48.7	57.8
35°C	child	44.7	2.5	7	42.4	47.0
	adult	52.9	3.7	7	49.5	56.3

APPENDIX A-2

METABOLIC EFFICIENCY (%)

Males

Climate	Status	Mean	Std.dev.	N	95%	confidence limits
22°C	child	12.7	1.8	8	11.1	14.2
	adult	18.9	2.0	9	17.4	20.4
31°C	child	12.9	2.1	8	11.2	14.7
	adult	18.9	1.1	9	18.1	19.8
35°C	child	12.2	1.6	8	10.9	13.6
	adult	19.2	1.2	9	18.2	20.1

Females

21°C	child	11.1	1.4	7	9.6	12.3
	adult	18.1	2.1	7	16.2	20.0
31°C	child	12.0	1.7	7	10.5	13.5
	adult	17.9	1.7	7	16.3	19.5
35°C	child	11.6	1.3	7	10.4	12.7
	adult	18.0	1.7	7	16.5	19.5

APPENDIX A-3

RELATIVE HEAT PRODUCTION (W.kg^{-1})

Climate	Status	Mean	Std.dev.	N	95%	confidence limits
	Males					
22°C	child	7.7	0.8	8	7.0	8.4
	adult	7.9	1.6	9	6.7	9.2
31°C	child	7.4	1.0	8	6.6	8.3
	adult	7.8	1.1	9	7.0	8.6
35°C	child	7.9	1.1	8	7.0	8.8
	adult	7.7	1.0	9	6.9	8.5
	Females					
22°C	child	6.2	0.7	7	5.6	6.8
	adult	7.1	1.2	7	5.9	8.2
31°C	child	5.6	0.5	7	5.2	6.1
	adult	7.1	0.9	7	6.2	7.9
35°C	child	5.9	0.9	7	5.1	6.7
	adult	7.1	1.1	7	6.1	8.1

APPENDIX A-4

RELATIVE EVAPORATIVE WEIGHT LOSS (gm.hr^{-1}.kg^{-1})

Males

Climate	Status	Mean	Std.dev.	N	95% confidence limits	
22°C	child	4.78	3.24	8	2.07	7.49
	adult	6.17	1.71	9	4.86	7.48
31°C	child	8.42	2.54	8	6.30	10.54
	adult	11.45	2.50	9	9.53	13.37
35°C	child	9.68	2.64	8	7.47	11.89
	adult	11.97	3.33	9	10.26	13.69

Females

Climate	Status	Mean	Std.dev.	N	95% confidence limits	
22°C	child	1.57	0 .87	7	0.77	2.37
	adult	2.57	0.66	7	1.96	3.18
31°C	child	5.68	2.50	7	3.36	7.99
	adult	6.80	2.33	7	4.65	8.95
35°C	child	7.48	2.71	7	4.97	9.98
	adult	11.36	6.14	7	5.68	17.04

APPENDIX A-5

EVAPORATIVE HEAT LOSS INDEX ($gm.hr^{-1}.W^{-1}$)

Males

Climate	Status	Mean	Std.dev.	N	95% confidence limits	
22°C	child	0.63	0.42	8	0.27	0.98
	adult	0.80	0.25	9	0.61	0.99
31°C	child	1.13	0.27	8	0.90	1.35
	adult	1.46	0.22	9	1.29	1.63
35°C	child	1.24	0.35	8	0.94	1.53
	adult	1.82	0.20	9	1.67	1.97

Females

Climate	Status	Mean	Std.dev.	N	95% confidence limits	
22°C	child	0.25	0.14	7	0.12	0.38
	adult	0.39	0.14	7	0.25	0.52
31°C	child	0.99	0.39	7	0.63	1.35
	adult	0.96	0.34	7	0.65	1.28
35°C	child	1.26	0.39	7	0.90	1.62
	adult	1.56	0.66	7	1.10	1.73

APPENDIX A-6

RELATIVE OXYGEN UPTAKE (ml.kg^{-1}.min^{-1})

Males

Time	Climate	Status	Mean	Std.dev.	N	95% confidence limits	
5 min	22°C	child	24.8	3.3	8	22.1	27.6
		adult	27.7	6.9	9	22.4	33.1
	31°C	child	25.6	4.0	8	22.1	28.9
		adult	26.8	3.8	9	23.9	29.7
	35°C	child	25.9	3.3	8	23.2	28.7
		adult	27.1	4.6	9	23.5	30.6
10min	22°C	child	25.7	4.1	8	22.2	29.2
		adult	28.7	5.2	9	24.7	32.7
	31°C	child	23.5	4.0	8	20.2	26.9
		adult	27.1	4.1	9	24.0	30.3
	35°C	child	24.9	3.0	8	22.4	27.4
		adult	27.7	4.0	9	24.1	30.8
15min	22°C	child	26.1	3.7	8	22.9	29.2
		adult	28.3	5.4	9	24.1	32.5
	31°C	child	24.2	2.7	8	21.9	26.7
		adult	28.8	5.0	9	25.0	32.6
	35°C	child	26.1	3.5	8	23.1	29.0
		adult	27.8	3.5	9	25.1	30.5
20min	22°C	child	26.2	3.3	8	23.5	30.0
		adult	29.0	5.3	9	24.9	33.0
	31°C	child	24.6	3.0	8	22.1	27.1
		adult	29.1	4.4	9	25.6	32.5
	35°C	child	27.2	3.9	8	23.9	30.4
		adult	28.0	3.5	9	25.3	30.7
25min	22°C	child	26.6	2.4	8	24.5	28.6
		adult	28.9	5.2	9	25.0	34.9
	31°C	child	25.8	3.8	8	22.6	29.1
		adult	29.6	3.0	9	27.3	31.9
	35°C	child	26.9	4.2	8	23.4	30.5
		adult	28.3	3.4	9	25.7	31.0
30min	22°C	child	27.0	3.3	8	24.3	30.0
		adult	29.2	5.5	9	25.1	33.4
	31°C	child	27.1	4.7	8	23.1	31.0
		adult	28.5	3.8	9	25.6	31.5
	35°C	child	27.8	5.0	8	23.6	32.0
		adult	28.7	3.5	9	26.0	31.3

Females

Time	Climate	Status	Mean	Std.dev.	N	95% confidence limits	
5min	22°C	child	20.3	1.7	7	18.7	21.9
		adult	24.6	4.2	7	20.7	28.6
	31°C	child	19.8	2.8	7	17.2	22.4
		adult	24.1	2.9	7	21.3	26.8
	35°C	child	17.8	2.8	7	15.1	20.3
		adult	25.6	3.4	7	22.5	28.7
10min	22°C	child	19.7	2.3	7	17.6	21.9
		adult	25.5	5.1	7	20.8	30.2
	31°C	child	19.6	4.4	7	15.6	23.6
		adult	25.2	3.2	7	22.2	28.1
	35°C	child	19.3	3.2	7	16.5	22.2
		adult	25.2	4.9	7	20.7	29.7
15min	22°C	child	20.9	2.5	7	18.5	23.2
		adult	25.3	4.3	7	21.3	29.3
	31°C	child	17.3	1.7	7	15.7	18.9
		adult	24.6	4.5	7	20.5	28.7
	35°C	child	20.0	4 7	7	17.5	22.5
		adult	25.6	4.4	7	21.6	29.6
20min	22°C	child	20.6	2.7	7	18.0	23.1
		adult	25.0	5.2	7	20.2	29.8
	31°C	child	18.2	1.6	7	16.8	19.7
		adult	26.1	3.8	7	22.6	29.6
	35°C	child	20.3	3.2	7	17.3	23.3
		adult	25.8	4.9	7	21.2	30.3
25min	22°C	child	21.4	3.4	7	18.2	24.6
		adult	25.5	5.0	7	20.9	30.1
	31°C	child	18.7	2.1	7	16.8	20.6
		adult	26.5	4.1	7	22.7	30.4
	35°C	child	20.2	3.7	7	16.7	23.5
		adult	25.2	3.9	7	21.6	28.8
30min	22°C	child	20.1	2.9	7	18.3	23.7
		adult	26.2	4.4	7	22.1	30.3
	31°C	child	19.3	2.5	7	17.0	21.7
		adult	26.5	4.7	7	22.1	30.8
	35°C	child	20.2	3.6	7	16.9	23.6
		adult	25.1	4.3	7	21.2	29.0

APPENDIX A-7

EAR CANAL TEMPERATURES (°C)

Females

Time	Climate	Status	Mean	Std.dev.	N	95%	confidence limits
5min	22°C	child	37.3	.31	7	37.0	37.6
		adult	37.0	.49	6	36.5	37.6
	31°C	child	37.6	.42	7	37.2	38.0
		adult	36.9	.37	6	36.5	37.3
	35°C	child	37.6	.31	7	37.3	37.8
		adult	37.2	.10	6	37.1	37.3
10min	22°C	child	37.1	.36	7	36.8	37.5
		adult	37.1	.56	6	36.5	37.7
	31°C	child	37.6	.43	7	37.2	38.0
		adult	37.0	.21	6	36.8	37.2
	35°C	child	37.6	.35	7	37.3	38.0
		adult	37.3	.14	6	37.2	37.5
15min	22°C	child	37.1	.37	7	36.8	37.4
		adult	37.1	.46	6	36.6	37.6
	31°C	child	37.6	.39	7	37.3	38.0
		adult	37.1	.26	6	36.8	37.4
	35°C	child	37.7	.34	7	37.4	38.0
		adult	37.4	.14	6	37.2	37.5
20min	22°C	child	37.1	.42	7	36.7	37.5
		adult	37.1	.51	6	36.7	37.6
	31°C	child	37.6	.37	7	37.3	38.0
		adult	37.1	.32	6	36.8	37.6
	35°C	child	37.7	.32	7	37.4	38.0
		adult	37.5	.21	6	37.2	37.7
25min	22°C	child	37.0	.45	7	36.6	37.4
		adult	37.1	.44	6	36.6	37.6
	31°C	child	37.6	.35	7	37.3	38.0
		adult	37.1	.42	6	36.7	37.5
	35°C	child	37.8	.35	7	37.5	38.1
		adult	37.5	.21	6	37.2	37.7
30min	22°C	child	36.9	.47	7	37.5	37.4
		adult	37.1	.43	6	36.6	37.5
	31°C	child	37.7	.28	7	37.4	37.9
		adult	37.1	.43	6	36.7	37.6
	35°C	child	37.8	.30	7	37.5	38.1
		adult	37.5	.29	6	37.2	37.8

EAR CANAL TEMPERATURES (°C)

Males

Time	Climate	Status	Mean	Std.dev.	N	95%	confidence limit
5mins	22°C	child	37.0	.52	7	36.5	37.5
		adult	36.5	.58	8	36.3	36.7
	31°C	child	37.4	.23	7	37.2	37.6
		adult	36.9	.53	8	36.4	37.3
	35°C	child	37.4	.36	7	37.1	37.8
		adult	37.1	.32	8	36.9	37.4
10mins	22°C	child	36.8	.44	7	36.4	37.2
		adult	36.4	.32	8	36.1	35.7
	31°C	child	37.5	.25	7	37.3	37.7
		adult	37.0	.51	8	36.6	37.4
	35°C	child	37.6	.29	7	37.3	37.8
		adult	37.2	.40	8	36.9	37.6
15mins	22°C	child	37.0	.50	7	36.5	37.4
		adult	36.4	.34	8	36.1	36.7
	31°C	child	37.4	.25	7	37.2	37.7
		adult	37.0	.45	8	36.7	37.4
	35°C	child	37.7	.19	7	37.5	37.9
		adult	37.3	.37	8	36.9	37.6
20mins	22°C	child	36.9	.47	7	36.5	37.4
		adult	36.5	.40	8	36.1	36.8
	31°C	child	37.5	.25	7	37.2	37.7
		adult	37.1	.40	8	36.7	37.4
	35°C	child	37.7	.22	7	37.5	37.9
		adult	37.3	.36	8	37.0	37.6
25mins	22°C	child	36.9	.50	7	36.5	37.4
		adult	36.4	.39	8	36.1	36.7
	31°C	child	37.4	.25	7	37.2	37.7
		adult	37.1	.25	8	36.7	37.4
	35°C	child	37.7	.22	7	37.5	37.9
		adult	37.3	.36	8	37.0	37.6
30mins	22°C	child	36.9	.54	7	36.4	37.3
		adult	36.3	.35	8	36.0	36.1
	31°C	child	37.5	.37	7	37.2	37.9
		adult	37.1	.37	8	36.8	37.4
	35°C	child	37.7	.26	7	37.5	38.0
		adult	37.3	.38	8	37.0	37.6

APPENDIX A-8

MEAN SKIN TEMPERATURE (°C)

Males

Time	Climate	Status	Mean	Std.dev.	N	95% confidence limits	
5min	22°C	child	27.8	1.2	8	26.8	28.8
		adult	29.3	1.7	9	28.0	30.5
	31°C	child	33.5	.6	8	33.1	34.1
		adult	33.7	.6	9	33.0	33.9
	35°C	child	34.9	.5	8	34.5	35.3
		adult	35.2	.6	9	34.7	35.7
10min	22°C	child	27.4	1.2	8	26.4	28.4
		adult	28.4	.9	9	27.7	29.1
	31°C	child	33.9	.9	8	33.1	34.7
		adult	33.9	.5	9	33.0	33.9
	35°C	child	35.2	.3	8	34.9	35.5
		adult	35.6	.4	9	35.2	36.0
15min	22°C	child	27.2	1.3	8	26.1	28.2
		adult	28.3	1.1	9	27.4	29.2
	31°C	child	34.0	.8	8	33.4	34.6
		adult	34.0	.6	9	33.5	34.5
	35°C	child	35.3	.3	8	35.1	35.5
		adult	35.7	.4	9	35.4	36.0
20min	22°C	child	27.0	1.2	8	26.0	28.1
		adult	28.3	1.3	9	27.2	29.3
	31°C	child	34.1	.7	8	33.4	34.7
		adult	34.1	.7	9	33.5	34.6
	35°C	child	35.5	.2	8	35.3	35.7
		adult	35.7	.4	9	35.4	36.0
25min	22°C	child	27.0	1.3	8	26.0	28.1
		adult	28.3	1.2	9	27.3	29.2
	31°C	child	34.2	.8	8	35.5	34.9
		adult	34.0	.7	9	33.4	34.6
	35°C	child	35.5	.2	8	35.4	35.7
		adult	35.7	.6	9	35.2	36.1
30min	22°C	child	27.1	1.3	8	26.0	28.1
		adult	28.3	1.0	9	27.5	29.1
	31°C	child	34.3	1.0	8	33.5	35.1
		adult	34.0	.8	9	33.4	34.6
	35°C	child	35.5	.3	8	35.3	35.8
		adult	35.7	.6	9	35.2	36.1

MEAN SKIN TEMPERATURE (°C)

Females

Time	Climate	Status	Mean	Std.dev.	N	95% confidence limits	
5min	22°C	child	29.0	.7	7	28.5	29.7
		adult	27.7	.8	7	27.0	28.5
	31°C	child	33.8	.7	7	33.7	34.4
		adult	33.5	.5	7	33.0	33.9
	35°C	child	35.1	.7	7	34.4	35.8
		adult	35.5	.8	7	34.8	36.2
10min	22°C	child	28.5	.9	7	27.7	28.3
		adult	27.2	.7	7	26.6	27.9
	31°C	child	34.0	.6	7	33.4	34.5
		adult	33.9	.6	7	33.3	34.4
	35°C	child	35.2	.6	7	34.6	35.7
		adult	35.9	.5	7	35.4	36.3
15min	22°C	child	28.5	.8	7	27.8	29.3
		adult	27.3	.8	7	26.5	28.0
	31°C	child	34.0	.5	7	33.6	34.5
		adult	34.2	.6	7	33.6	34.7
	35°C	child	35.3	.6	7	34.8	35.9
		adult	36.0	.4	7	35.6	36.4
20min	22°C	child	28.3	.9	7	27.6	29.1
		adult	27.3	.9	7	26.5	28.1
	31°C	child	34.0	.5	7	33.5	34.4
		adult	34.3	.4	7	33.9	34.7
	35°C	child	35.5	.6	7	36.0	36.0
		adult	36.1	.3	7	35.8	36.4
25min	22°C	child	28.5	.9	7	27.7	29.4
		adult	27.4	.9	7	26.6	28.2
	31°C	child	34.0	.4	7	33.6	34.4
		adult	34.3	.4	7	34.0	34.7
	35°C	child	35.5	.5	7	35.1	36.0
		adult	36.2	.4	7	35.8	36.5
30min	22°C	child	28.6	.8	7	27.8	29.4
		adult	27.5	.9	7	26.6	28.3
	31°C	child	34.0	.4	7	33.6	34.4
		adult	34.4	.3	7	34.1	34.7
	35°C	child	35.5	.5	7	35.1	36.0
		adult	36.1	.4	7	35.8	36.4

APPENDIX A-9

HEART RATE (b.min^{-1})

Females

Time	Climate	Status	Mean	Std.dev.	N	95% confidence limits	
5min	22°C	child	130	8	7	122	136
		adult	120	15	7	105	134
	31°C	child	138	8	7	130	146
		adult	125	15	7	110	139
	35°C	child	141	15	7	127	155
		adult	127	13	7	115	139
10min	22°C	child	132	7	7	124	139
		adult	122	18	7	107	137
	31°C	child	140	12	7	129	151
		adult	126	13	7	113	138
	35°C	child	144	13	7	132	156
		adult	132	11	7	121	142
15min	21°C	child	136	8	7	128	143
		adult	124	19	7	107	142
	31°C	child	136	8	7	129	144
		adult	128	15	7	114	142
	35°C	child	149	11	7	139	159
		adult	134	12	7	123	145
20min	22°C	child	138	8	7	131	146
		adult	123	17	7	108	139
	31°C	child	141	9	7	133	149
		adult	132	16	7	117	147
	35°C	child	153	13	7	140	165
		adult	137	13	7	125	150
25min	22°C	child	141	8	7	132	148
		adult	122	16	7	107	137
	31°C	child	143	10	7	133	152
		adult	134	17	7	118	150
	35°C	child	154	14	7	141	167
		adult	139	16	7	124	154
30min	22°C	child	144	10	7	134	153
		adult	124	15	7	111	138
	31°C	child	144	12	7	133	155
		adult	136	17	7	119	151
	35°C	child	159	13	7	147	171
		adult	139	19	7	121	156

HEART RATE (b.min^{-1})

Time	Climate	Males Status	Mean	Std.dev.	N	95% confidence limits	
5min	22°C	child	127	11	7	117	138
		adult	118	10	9	110	125
	31°C	child	143	11	7	133	154
		adult	123	7	9	118	128
	35°C	child	146	10	7	137	156
		adult	125	11	9	116	134
10min	22°C	child	136	12	7	125	147
		adult	117	7	9	112	122
	31°C	child	142	14	7	129	155
		adult	124	9	9	117	130
	35°C	child	150	11	7	141	160
		adult	126	13	9	116	136
15min	22°C	child	139	13	7	127	151
		adult	118	7	9	113	124
	31°C	child	141	8	7	134	148
		adult	126	8	9	119	132
	35°C	child	153	11	7	143	163
		adult	126	14	9	115	137
20min	22°C	child	140	8	7	133	148
		adult	118	9	9	111	125
	31°C	child	145	9	7	137	153
		adult	126	10	9	119	135
	35°C	child	158	12	7	147	169
		adult	127	14	9	117	138
25min	22°C	child	139	10	7	129	148
		adult	116	9	9	109	123
	31°C	child	148	10	7	139	157
		adult	129	10	9	122	137
	35°C	child	160	10	7	151	169
		adult	127	13	9	117	136
30min	22°C	child	140	12	7	129	151
		adult	117	7	9	112	123
	31°C	child	153	16	7	138	167
		adult	129	11	9	120	137
	35°C	child	165	14	7	152	177
		adult	128	13	9	117	138

APPENDIX A-10

PERCENTAGE HEART RATE MAXIMUM

Males

Time	climate	status	mean	std.dev	N	95% confidence limits	
5mins	22°C	child	64.6	6.7	7	58.4	70.8
		adult	60.8	5.2	9	56.8	64.9
	31°C	child	72.5	4.2	7	68.6	76.4
		adult	63.7	3.0	9	61.4	66.0
	35°C	child	74.0	4.0	7	70.3	77.7
		adult	64.7	4.7	9	61.0	68.3
10mins	22°C	child	68.9	6.9	7	62.5	75.3
		adult	60.7	2.6	9	58.7	62.7
	31°C	child	71.7	6.4	7	65.8	77.7
		adult	64.1	3.8	9	61.1	67.0
	35°C	child	76.1	4.1	7	72.2	79.9
		adult	65.1	5.5	9	60.9	69.3
15mins	22°C	child	70.3	6.1	7	64.6	76.0
		adult	61.2	2.5	9	59.3	63.1
	31°C	child	71.3	3.9	7	67.7	75.0
		adult	65.1	3.9	9	62.1	68.0
	35°C	child	77.4	4.1	7	73.6	81.3
		adult	65.0	6.1	9	60.3	69.8
20mins	22°C	child	70.9	3.6	7	67.6	74.2
		adult	60.9	3.5	9	58.2	63.6
	31°C	child	73.2	3.3	7	70.1	76.4
		adult	65.6	4.5	9	62.1	69.1
	35°C	child	79.9	4.7	7	75.6	84.3
		adult	65.8	6.0	9	61.2	70.4
25min	22°C	child	70.2	5.4	7	65.2	75.2
		adult	60.1	3.4	9	57.5	62.8
	31°C	child	74.7	4.0	7	71.0	78.4
		adult	66.9	4.3	9	63.6	70.3
	35°C	child	81.1	3.0	7	78.3	83.9
		adult	65.4	5.5	9	61.2	69.6
30mins	22°C	child	70.7	6.1	7	65.1	76.4
		adult	60.7	2.7	9	58.6	62.8
	31°C	child	77.1	5.9	7	71.7	82.6
		adult	66.6	4.6	9	63.0	70.1
	35°C	child	83.1	4.6	7	78.9	87.4
		adult	65.9	5.6	9	61.6	70.2

PERCENTAGE HEART RATE MAXIMUM

Females

Time	climate	status	mean	std.dev	N	95% confidence limits	
5mins	22°C	child	66.4	6.8	7	60.1	72.6
		adult	63.3	8.5	7	55.5	71.2
	31°C	child	70.7	5.6	7	65.5	75.9
		adult	65.9	7.7	7	58.8	73.1
	35°C	child	71.7	5.6	7	66.5	76.9
		adult	67.2	6.1	7	61.5	72.9
10mins	22°C	child	67.5	6.9	7	61.0	73.9
		adult	64.6	8.9	7	56.3	72.9
	31°C	child	71.5	8.1	7	64.0	79.0
		adult	66.5	6.5	7	60.5	72.5
	35°C	child	73.4	5.2	7	68.6	78.3
		adult	69.7	4.9	7	65.2	74.3
15mins	22°C	child	69.5	6.7	7	63.3	75.7
		adult	65.9	9.7	7	56.9	74.8
	31°C	child	69.8	5.4	7	64.8	74.8
		adult	67.7	7.1	7	61.1	74.3
	35°C	child	75.9	4.4	7	71.8	79.9
		adult	71.0	4.7	7	66.7	75.3
20mins	22°C	child	70.9	6.7	7	64.7	77.2
		adult	65.3	8.6	7	57.4	73.3
	31°C	child	72.2	5.7	7	66.8	77.6
		adult	69.7	7.7	7	62.6	76.8
	35°C	child	78.0	5.6	7	72.8	83.2
		adult	72.6	5.8	7	67.2	78.0
25mins	22°C	child	72.1	7.4	7	65.2	78.9
		adult	64.8	8.6	7	56.9	72.7
	31°C	child	73.1	7.3	7	66.4	79.8
		adult	70.9	7.9	7	63.6	78.2
	35°C	child	78.4	6.2	7	72.7	84.2
		adult	73.4	7.0	7	66.9	79.8
30mins	22°C	child	73.8	8.1	7	66.3	81.3
		adult	65.8	7.8	7	58.6	73.0
	31°C	child	73.9	8.2	7	66.4	81.5
		adult	71.7	8.1	7	64.2	79.1
	35°C	child	81.2	5.8	7	75.9	86.6
		adult	73.4	8.8	7	65.2	81.5

APPENDIX A-11

HEART RATE INDEX (% Heart rate max. % VO_2max^{-1})

Males

Time	climate	status	mean	std.dev	N	95% confidence limits	
5mins	22°C	child	1.30	.12	7	1.19	1.41
		adult	1.26	.14	9	1.15	1.36
	31°C	child	1.53	.07	7	1.46	1.59
		adult	1.32	.08	9	1.26	1.39
	35°C	child	1.48	.11	7	1.38	1.58
		adult	1.37	.15	9	1.25	1.48
10mins	22°C	child	1.39	.14	7	1.26	1.51
		adult	1.26	.16	9	1.13	1.39
	31°C	child	1.51	.08	7	1.44	1.58
		adult	1.33	.11	9	1.25	1.42
	35°C	child	1.52	.12	7	1.41	1.63
		adult	1.37	.15	9	1.26	1.49
15mins	22°C	child	1.42	.15	7	1.28	1.56
		adult	1.27	.16	9	1.15	1.40
	31°C	child	1.51	.10	7	1.41	1.60
		adult	1.35	.11	9	1.27	1.44
	35°C	child	1.55	.12	7	1.44	1.65
		adult	1.37	.17	9	1.24	1.51
20mins	22°C	child	1.43	.11	7	1.33	1.53
		adult	1.26	.16	9	1.14	1.38
	31°C	child	1.55	.10	7	1.45	1.64
		adult	1.37	.13	9	1.27	1.47
	35°C	child	1.60	.11	7	1.49	1.70
		adult	1.39	.18	9	1.25	1.53
25mins	22°C	child	1.42	.12	7	1.31	1.53
		adult	1.25	.17	9	1.12	1.38
	31°C	child	1.58	.13	7	1.45	1.70
		adult	1.40	.15	9	1.28	1.51
	35°C	child	1.62	.10	7	1.52	1.71
		adult	1.38	.17	9	1.25	1.51
30mins	22°C	child	1.43	.14	7	1.30	1.55
		adult	1.26	.15	9	1.14	1.38
	31°C	child	1.63	.09	7	1.54	1.70
		adult	1.38	.15	9	1.27	1.51
	35°C	child	1.66	.09	7	1.58	1.74
		adult	1.39	.17	9	1.26	1.53

HEART RATE INDEX (% Heart rate max. % VO_2max^{-1})

Time	climate	Female status	mean	std.dev	N	95% confidence limits	
5mins	22°C	child	1.40	.16	7	1.25	1.55
		adult	1.22	.28	7	0.96	1.48
	31°C	child	1.65	.24	7	1.43	1.87
		adult	1.25	.21	7	1.06	1.45
	35°C	child	1.61	.15	7	1.47	1.74
		adult	1.28	.20	7	1.09	1.47
10mins	22°C	child	1.42	.14	7	1.30	1.55
		adult	1.24	.29	7	0.97	1.51
	31°C	child	1.66	.24	7	1.44	1.88
		adult	1.26	.21	7	1.07	1.46
	35°C	child	1.64	.12	7	1.53	1.76
		adult	1.33	.18	7	1.16	1.50
15mins	22°C	child	1.47	.14	7	1.34	1.60
		adult	1.27	.31	7	0.98	1.56
	31°C	child	1.62	.18	7	1.46	1.79
		adult	1.29	.22	7	1.08	1.49
	35°C	child	1.70	.11	7	1.59	1.81
		adult	1.35	.18	7	1.19	1.52
20mins	22°C	child	1.50	.14	7	1.38	1.63
		adult	1.26	.28	7	1.00	1.52
	31°C	child	1.68	.15	7	1.53	1.82
		adult	1.33	.23	7	1.11	1.54
	35°C	child	1.75	.13	7	1.62	1.87
		adult	1.38	.19	7	1.21	1.56
25mins	22°C	child	1.52	.15	7	1.39	1.66
		adult	1.25	.28	7	0.99	1.51
	31°C	child	1.70	.19	7	1.52	1.87
		adult	1.35	.24	7	1.13	1.57
	35°C	child	1.76	.15	7	1.62	1.90
		adult	1.40	.20	7	1.22	1.58
30mins	22°C	child	1.56	.13	7	1.44	1.68
		adult	1.27	.26	7	1.02	1.51
	31°C	child	1.71	.20	7	1.53	1.89
		adult	1.36	.24	7	1.14	1.59
	35°C	child	1.82	.13	7	1.69	1.94
		adult	1.40	.22	7	1.19	1.61

APPENDIX B-1

AIR TEMPERATURE- CONSTANT METABOLISM (°C)

Time	Status	Mean	Std.dev.	N	95%	confidence limits
	Low Radiant					
5mins	adult	30.9	.3	9	30.6	31.1
	child	31.1	.3	10	30.9	31.3
10mins	adult	31.1	.3	9	30.8	31.4
	child	31.1	.3	10	30.9	31.3
15mins	adult	31.1	.3	9	30.8	31.4
	child	31.4	.5	10	31.0	31.8
20mins	adult	31.5	.7	9	31.0	32.0
	child	31.9	.5	10	31.5	32.3
25mins	adult	31.7	.6	9	31.2	32.1
	child	31.9	.5	10	31.5	32.3
30mins	adult	31.7	.5	9	31.3	32.1
	child	32.0	.4	10	31.8	32.3
35mins	adult	31.9	.5	9	31.6	32.3
	child	32.1	.3	10	31.9	32.3
40mins	adult	32.1	.3	9	31.8	32.4
	child	32.1	.3	10	31.9	32.3
	High Radiant					
5mins	adult	30.8	.4	9	30.4	31.1
	child	31.0	.5	10	30.7	31.3
10mins	adult	31.2	.4	9	30.9	31.6
	child	31.2	.4	10	30.9	31.5
15mins	adult	31.8	.4	9	31.6	32.1
	child	32.0	.6	10	31.5	32.4
20mins	adult	32.6	.5	9	32.2	33.0
	child	32.3	.7	10	31.8	32.8
25mins	adult	33.1	.6	9	32.6	33.6
	child	32.8	.6	10	32.3	33.2
30mins	adult	33.4	.8	9	32.8	34.0
	child	33.2	.7	10	32.7	33.6
35mins	adult	33.9	1.0	9	33.1	34.6
	child	33.7	.7	10	33.2	34.3
40mins	adult	34.2	1.2	9	33.3	35.1
	child	33.9	.7	10	33.4	34.4

APPENDIX B-2

RELATIVE HUMIDITY - CONSTANT METABOLISM (%)

Time	Status	Mean	Std.dev.	N	95%	confidence limits
	Low Radiant					
5mins	adult	77.7	10.1	8	69.3	86.3
	child	83.1	9.9	8	74.2	91.4
15mins	adult	73.9	10.0	8	65.5	82.2
	child	79.9	3.9	8	76.6	83.2
25mins	adult	69.0	10.1	8	60.5	77.5
	child	74.4	4.0	8	71.2	77.5
35mins	adult	69.2	9.6	8	61.2	77.3
	child	74.7	2.2	8	72.9	76.6
	High Radiant					
5mins	adult	71.7	8.3	8	64.9	78.6
	child	82.3	13.4	8	71.8	93.5
15mins	adult	71.6	2.1	8	69.8	73.3
	child	71.5	8.0	8	64.8	78.2
25mins	adult	65.2	3.5	8	62.3	68.2
	child	72.6	3.2	8	69.9	75.3
35mins	adult	63.2	4.9	8	59.1	67.4
	child	68.6	2.7	8	66.3	70.9

APPENDIX B-3

AVERAGE METABOLISM - CONSTANT METABOLISM (W.)

Status	Mean	Std.dev.	N	95% confidence limits	
Low Radiant					
adult	656	88	9	589	724
child	297	47	10	264	331
High Radiant					
adult	667	70	9	613	721
child	294	41	10	264	323

RELATIVE HEAT PRODUCTION - CONSTANT METABOLISM ($W.kg.^{-1}$)

Low Radiant					
adult	7.3	1.2	9	6.4	8.2
child	7.1	1.3	10	6.4	8.3
High Radiant					
adult	7.4	1.0	9	6.6	8.3
child	7.2	1.0	10	6.5	7.9

PERCENTAGE OXYGEN UPTAKE - CONSTANT METABOLISM

Low Radiant					
adult	50.1	2.6	9	48.1	52.1
child	46.7	6.2	10	42.2	51.1
High Radiant					
adult	51.0	3.4	9	48.4	53.7
child	46.1	4.0	10	47.2	49.6

METABOLIC EFFICIENCY - CONSTANT METABOLISM (%)

Low Radiant					
adult	18.4	1.7	9	17.1	19.7
child	12.1	1.6	10	11.0	13.2
High Radiant					
adult	18.1	1.8	9	16.6	19.5
child	12.1	1.5	10	11.1	13.3

APPENDIX B-4

RELATIVE SWEAT RATE - CONSTANT METABOLISM ($g.hr^{-1}.kg.^{-1}$)

Status	Mean	Std.dev.	N	95% confidence limits	
	Low Radiant				
adult	9.4	2.2	9	7.7	11.1
child	8.9	1.7	10	7.7	10.2
	High Radiant				
adult	11.4	3.4	9	8.8	14.0
child	10.6	1.5	10	9.5	11.7

SWEAT HEAT LOSS INDEX - CONSTANT METABOLISM ($g.hr^{-1}.W.^{-1}$)

	Low Radiant				
adult	1.30	.29	9	1.07	1.51
child	1.22	.16	10	1.11	1.33
	High Radiant				
adult	1.54	.43	9	1.21	1.88
child	1.48	.13	10	1.38	1.57

APPENDIX B-5

OXYGEN UPTAKE - CONSTANT METABOLISM (ml.kg^{-1}.min^{-1})

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	24.9	4.0	9	21.8	27.9
	child	25.4	4.1	10	22.4	28.4
10mins	adult	25.8	4.9	9	22.0	29.5
	child	25.5	4.9	10	21.9	28.9
15mins	adult	26.1	4.7	9	22.5	29.7
	child	23.6	5.1	10	19.9	27.3
20mins	adult	26.8	5.2	9	22.9	30.8
	child	23.4	6.0	10	19.2	27.7
25mins	adult	26.8	4.8	9	23.2	30.5
	child	24.5	4.4	10	21.4	27.6
30mins	adult	26.8	4.8	9	23.1	30.6
	child	23.9	4.7	10	20.5	27.2
35mins	adult	26.7	5.2	9	22.8	30.7
	child	24.7	4.5	10	21.4	27.9
40mins	adult	26.4	4.6	9	22.9	30.0
	child	25.0	4.4	10	21.9	28.2

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	25.0	4.0	9	21.9	28.1
	child	25.0	4.3	10	21.9	28.1
10mins	adult	26.0	4.3	9	22.8	29.3
	child	23.6	3.9	10	20.8	26.4
15mins	adult	27.2	4.7	9	23.6	30.7
	child	22.3	3.0	10	20.1	24.5
20mins	adult	27.5	4.4	9	24.1	30.9
	child	23.8	3.1	10	21.5	26.1
25mins	adult	26.5	4.1	9	23.4	29.7
	child	23.7	4.1	10	20.7	26.6
30mins	adult	26.9	4.3	9	23.6	30.2
	child	24.3	3.4	10	21.9	26.8
35mins	adult	27.4	4.2	9	24.2	30.7
	child	24.6	3.0	10	22.4	26.7
40mins	adult	27.4	4.2	9	24.2	30.7
	child	25.6	4.3	10	22.5	28.7

APPENDIX B-6

HEART RATE - CONSTANT METABOLISM (b.min^{-1})

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	112	8	9	106	118
	child	138	14	10	128	148
10mins	adult	117	7	9	111	122
	child	141	15	10	131	152
15mins	adult	119	8	9	113	125
	child	140	13	10	131	150
20mins	adult	120	7	9	115	126
	child	141	11	10	133	149
25mins	adult	123	8	9	117	129
	child	145	13	10	136	154
30mins	adult	124	8	9	118	131
	child	145	14	10	135	155
35mins	adult	123	7	9	118	131
	child	145	14	10	139	157
40mins	adult	124	6	9	119	129
	child	149	13	10	140	158

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	110	8	9	103	116
	child	130	11	10	122	139
10mins	adult	115	7	9	110	121
	child	135	12	10	125	144
15mins	adult	120	9	9	113	126
	child	136	11	10	128	144
20mins	adult	123	9	9	116	130
	child	141	12	10	132	150
25mins	adult	124	9	9	117	130
	child	148	14	10	138	158
30mins	adult	127	9	9	120	134
	child	149	15	10	138	160
35mins	adult	130	10	9	122	137
	child	150	15	10	139	161
40mins	adult	132	11	9	124	141
	child	155	15	10	144	166

APPENDIX B-7

PERCENTAGE HEART RATE MAXIMUM - CONSTANT METABOLISM

Time	Status	Mean	Std.dev.	N	95%	confidence limits
	Low Radiant					
5min	adult	59.5	3.8	9	56.5	62.5
	child	68.9	5.2	10	65.1	72.6
10mins	adult	62.0	3.8	9	59.1	64.9
	child	70.7	5.6	10	66.7	74.7
15mins	adult	63.3	3.9	9	60.3	66.4
	child	70.2	5.0	10	66.6	73.8
20mins	adult	63.9	4.1	9	60.8	67.1
	child	70.7	5.4	10	66.9	74.5
25min	adult	65.5	3.8	9	62.6	68.4
	child	72.5	5.5	10	68.6	76.4
30mins	adult	66.2	3.9	9	63.2	69.2
	child	72.5	6.1	10	68.1	76.9
35mins	adult	65.5	3.9	9	62.6	68.5
	child	74.3	5.6	10	70.3	78.3
40mins	adult	65.9	3.5	9	63.2	68.6
	child	74.6	5.2	10	70.9	78.3
	High Radiant					
5mins	adult	58.3	4.5	9	54.3	61.8
	child	65.4	4.9	10	61.8	68.0
10mins	adult	61.5	3.7	9	58.7	64.3
	child	67.4	4.0	10	64.5	70.2
15mins	adult	63.6	4.7	9	60.1	67.3
	child	68.1	4.6	10	64.8	71.3
20mins	adult	65.5	4.9	9	61.7	69.3
	child	70.7	4.1	10	67.8	73.6
25mins	adult	65.8	4.9	9	62.0	69.6
	child	73.9	4.4	10	70.7	77.1
30mins	adult	67.7	5.1	9	63.8	71.7
	child	74.7	4.7	10	71.3	78.0
35mins	adult	69.2	5.7	9	64.8	73.6
	child	75.2	5.2	10	71.5	79.0
40mins	adult	70.5	6.2	9	65.8	75.2
	child	77.5	4.5	10	74.2	78.9

APPENDIX B-8

HEART RATE INDEX CONSTANT METABOLISM

(% Heart rate max.% VO_2max^{-1})

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	1.25	.07	9	1.20	1.32
	child	1.43	.19	10	1.30	1.58
10mins	adult	1.27	.08	9	1.21	1.33
	child	1.49	.25	10	1.31	1.66
15mins	adult	1.28	.11	9	1.19	1.36
	child	1.61	.30	10	1.39	1.82
20mins	adult	1.25	.04	9	1.22	1.29
	child	1.65	.32	19	1.42	1.88
25mins	adult	1.29	.12	9	1.19	1.38
	child	1.58	.23	10	1.41	1.74
30mins	adult	1.30	.12	9	1.21	1.40
	child	1.63	.28	10	1.43	1.82
35mins	adult	1.30	.14	9	1.19	1.41
	child	1.60	.18	10	1.47	1.73
40mins	adult	1.32	.14	9	1.21	1.42
	child	1.58	.19	10	1.44	1.72

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	1.23	.15	9	1.12	1.35
	child	1.39	.22	10	1.24	1.55
10mins	adult	1.25	.12	9	1.15	1.34
	child	1.51	.21	0	1.36	1.67
15mins	adult	1.24	.11	9	1.15	1.32
	child	1.62	.23	10	1.45	1.78
20mins	adult	1.25	.10	9	1.17	1.33
	child	1.56	.16	10	1.45	1.68
25mins	adult	1.30	.11	9	1.22	1.39
	child	1.66	.16	10	1.54	1.77
30mins	adult	1.33	.13	9	1.22	1.43
	child	1.62	.16	10	1.50	1.73
35mins	adult	1.33	.15	9	1.21	1.44
	child	1.61	.19	10	1.48	1.75
40mins	adult	1.35	.15	9	1.24	1.47
	child	1.61	.20	10	1.47	1.75

APPENDIX B-9

MEAN SKIN TEMPERATURE-NOT EXPOSED TO RADIANT HEAT. CONSTANT METABOLISM (°C)

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	32.9	.6	9	32.4	33.3
	child	34.0	.6	10	33.6	34.5
10mins	adult	32.9	.6	9	32.5	33.4
	child	33.7	.6	10	33.3	34.2
15mins	adult	32.9	.6	10	32.4	33.4
	child	34.1	.7	10	33.6	34.6
20mins	adult	32.9	.7	9	32.4	33.5
	child	34.1	.8	10	33.5	34.7
25mins	adult	33.0	.6	9	32.5	33.5
	child	34.1	.8	10	33.5	34.8
30mins	adult	33.0	.7	9	32.5	33.6
	child	34.1	.8	10	33.5	34.8
35mins	adult	33.2	.8	9	32.6	33.8
	child	34.1	.8	10	33.5	34.6
40mins	adult	33.1	.8	9	32.4	33.8
	child	34.2	.8	10	33.6	34.8

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	33.1	.7	9	32.6	33.7
	child	33.6	.6	10	33.2	34.0
10mins	adult	32.8	.6	9	32.3	33.3
	child	33.5	.6	10	33.1	34.0
15mins	adult	33.4	.6	9	32.9	33.9
	child	34.0	.7	10	33.4	34.5
20mins	adult	33.5	.6	9	33.0	33.9
	child	34.1	.8	10	33.5	34.7
25mins	adult	33.7	.7	9	33.1	34.2
	child	34.2	.6	10	33.8	34.6
30mins	adult	33.7	.6	9	33.3	34.2
	child	34.3	.6	10	33.8	34.7
35mins	adult	33.8	.7	9	33.2	34.3
	child	34.4	.7	10	33.9	34.9
40mins	adult	33.9	.9	9	33.2	34.6
	child	34.4	.8	10	33.8	34.9

APPENDIX B-10

MEAN SKIN TEMPERATURE -EXPOSED TO RADIANT HEAT. CONSTANT METABOLISM (°C)

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	32.1	.6	9	31.6	32.6
	child	33.9	.4	10	33.6	34.2
10mins	adult	32.1	.5	9	31.7	32.5
	child	33.8	.6	10	33.4	34.2
15mins	adult	33.8	.5	9	33.4	34.2
	child	35.6	.8	10	35.0	36.1
20mins	adult	33.9	.7	9	33.4	34.5
	child	35.8	.7	10	35.3	36.3
25mins	adult	34.2	.6	9	33.7	34.7
	child	35.8	.8	10	35.3	36.4
30mins	adult	34.3	.6	9	33.9	34.7
	child	35.7	.7	10	35.2	36.2
35mins	adult	34.3	.6	9	33.8	34.8
	child	35.8	.8	10	35.2	36.4
40mins	adult	34.4	.6	9	33.9	34.9
	child	35.7	.8	10	35.2	36.3

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	32.3	1.0	9	31.5	33.1
	child	33.9	.4	10	33.6	34.1
10mins	adult	31.7	.8	9	31.0	32.4
	child	33.4	.4	10	33.1	33.7
15mins	adult	36.7	.7	9	36.2	37.3
	child	38.4	.5	10	38.0	38.7
20mins	adult	37.3	.7	9	36.7	37.8
	child	39.0	.5	10	38.6	39.4
25mins	adult	37.5	.7	9	36.9	38.0
	child	39.0	.5	10	38.6	39.4
30mins	adult	37.7	.7	9	37.1	38.1
	child	39.1	.6	10	38.6	39.5
35mins	adult	37.7	.7	9	37.1	38.2
	child	39.1	.5	10	38.7	39.4
40mins	adult	37.8	.7	9	37.2	38.3
	child	38.9	.5	10	38.5	39.3

CORE TEMPERATURE - CONSTANT METABOLISM (°C)

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	37.2	.4	9	36.9	37.5
	child	37.5	.3	10	37.3	37.7
10mins	adult	37.2	.5	9	36.9	37.6
	child	37.6	.4	10	37.3	37.8
15mins	adult	37.3	.5	9	36.9	37.6
	child	37.6	.3	10	37.3	37.8
20mins	adult	37.3	.5	9	36.9	37.6
	child	37.5	.3	10	37.3	37.8
25mins	adult	37.2	.5	9	36.8	37.6
	child	37.5	.3	10	37.2	37.7
30mins	adult	37.2	.5	9	36.9	37.6
	child	37.5	.3	10	37.2	37.7
35mins	adult	37.2	.5	9	36.9	37.6
	child	37.5	.3	10	37.3	37.7
40mins	adult	37.3	.5	9	36.9	37.6
	child	37.5	.3	10	37.3	37.7

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	37.1	.2	9	36.9	37.3
	child	37.4	.3	10	37.2	37.6
10mins	adult	37.2	.2	9	37.0	37.3
	child	37.5	.3	10	37.3	37.7
15mins	adult	37.2	.2	9	37.1	37.3
	child	37.5	.3	10	37.3	37.7
20mins	adult	37.2	.2	9	37.1	37.4
	child	37.5	.2	10	37.4	37.7
25mins	adult	37.3	.2	9	37.1	37.4
	child	37.5	.3	10	37.3	37.7
30mins	adult	37.3	.3	9	37.1	37.5
	child	37.6	.3	10	37.4	37.8
35mins	adult	37.3	.3	9	37.1	37.6
	child	37.6	.3	10	37.4	37.8
40mins	adult	37.4	.3	9	37.1	37.6
	child	37.6	.3	10	37.4	37.8

APPENDIX B-12

AIR TEMPERATURE - INCREASING METABOLISM (°C)

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	31.0	.5	10	30.7	31.3
	child	31.0	.0	10	31.0	31.0
10mins	adult	31.4	.5	10	31.0	31.8
	child	31.6	.5	10	31.2	32.0
15mins	adult	31.8	.5	10	31.5	32.2
	child	31.9	.3	10	31.7	32.1
20mins	adult	32.0	.7	10	31.5	32.5
	child	32.1	.3	10	31.9	32.2
25mins	adult	32.1	.6	10	31.7	32.6
	child	32.2	.4	10	31.9	32.5
30mins	adult	32.1	.6	10	31.7	32.6
	child	32.2	.4	10	31.9	32.5

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	31.1	.3	10	30.9	31.3
	child	31.0	.0	10	31.0	31.0
10mins	adult	31.8	.7	10	31.3	32.3
	child	32.1	.6	10	31.7	32.5
15mins	adult	32.4	.6	10	32.0	32.9
	child	32.9	.6	10	32.5	33.3
20mins	adult	33.1	.5	10	32.7	33.5
	child	33.2	.8	10	32.7	33.7
25mins	adult	33.5	.6	10	33.1	34.0
	child	33.5	.7	10	33.0	34.0
30mins	adult	33.6	.7	10	33.2	34.1
	child	33.6	.8	10	33.1	34.2

RELATIVE HUMIDITY - INCREASING METABOLISM (%)

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	74.1	5.9	9	69.6	78.6
	child	89.9	9.6	10	83.1	96.7
15mins	adult	71.4	3.6	9	68.7	74.2
	child	80.4	6.4	10	75.8	85.0
25mins	adult	70.3	4.2	9	67.1	75.6
	child	73.6	4.4	10	70.4	76.8

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	67.1	6.0	9	63.4	72.4
	child	74.6	6.6	10	69.8	79.4
15mins	adult	67.9	5.9	9	63.4	72.4
	child	72.7	4.9	10	69.2	76.2
25mins	adult	65.2	3.8	9	62.3	68.1
	child	70.9	4.5	10	67.7	74.1

APPENDIX B-13

AVERAGE METABOLISM - INCREASING METABOLISM (w.)

Time	Status	Mean	Std.dev.	N	95%	confidence limits
	Low Radiant					
5-10m	adult	488	68	10	440	537
	child	232	33	10	208	256
15-20m	adult	636	84	10	576	697
	child	281	40	10	253	310
25-30m	adult	816	89	10	752	880
	child	377	65	10	330	424
	High Radiant					
5-10m	adult	502	43	10	471	533
	child	247	60	10	204	291
15-20m	adult	642	71	10	591	693
	child	330	66	10	283	377
25-30m	adult	852	90	10	787	916
	child	410	80	10	353	468

PERCENTAGE MAXIMUM OXYGEN UPTAKE - INCREASING METABOLISM

	Low Radiant					
5-10m	adult	38.2	3.5	10	35.7	40.6
	child	36.4	3.7	10	33.8	39.0
15-20m	adult	49.7	3.9	10	47.0	52.5
	child	44.1	4.7	10	41.0	47.5
25-30m	adult	63.8	3.1	10	61.6	66.0
	child	58.9	6.1	10	54.5	63.2
	High Radiant					
5-10m	adult	39.3	2.9	10	37.3	41.5
	child	38.2	5.5	10	34.2	42.2
15-20m	adult	50.2	3.0	10	48.1	52.4
	child	51.3	5.7	10	47.2	55.4
25-30m	adult	66.6	4.5	10	64.1	69.1
	child	63.8	6.4	10	59.2	68.4

METABOLIC EFFICIENCY - INCREASING METABOLISM (%)

Time	Status	Mean	Std.dev.	N	95% confidence limits	
Low Radiant						
5-10m	adult	16.7	2.3	10	15.1	18.4
	child	9.6	2.6	10	7.7	11.5
15-20m	adult	18.4	1.9	10	17.0	19.8
	child	13.2	1.5	10	12.2	14.3
25-30m	adult	19.6	1.9	10	18.2	21.0
	child	13.9	.7	10	13.4	14.4
High Radiant						
5-10m	adult	16.3	2.9	10	14.2	18.5
	child	8.9	1.9	10	7.5	10.2
15-20m	adult	18.2	2.2	10	16.6	19.8
	child	11.5	1.0	10	10.8	12.2
25-30m	adult	18.9	2.2	10	17.3	20.5
	child	13.0	1.2	10	12.1	13.9

RELATIVE HEAT PRODUCTION - INCREASING METABOLISM ($W.kg^{-1}$)

Time	Status	Mean	Std.dev.	N	95% confidence limits	
Low Radiant						
5-10m	adult	5.6	1.0	10	4.9	6.3
	child	5.8	.5	10	5.5	6.1
15-20m	adult	7.1	1.2	10	6.3	8.0
	child	6.8	.9	10	6.2	7.4
25-30m	adult	9.0	1.2	10	8.1	9.9
	child	9.0	1.2	10	8.1	9.9
High Radiant						
5-10m	adult	5.7	.6	10	5.3	6.2
	child	6.2	1.0	10	5.4	6.9
15-20m	adult	7.2	1.0	10	6.5	7.9
	child	8.1	1.2	10	7.2	8.9
25-30m	adult	9.5	1.3	10	8.5	10.4
	child	9.9	.4	10	8.8	10.9

APPENDIX B-14

RELATIVE SWEAT RATE ($g.hr^{-1}.kg^{-1}$.)

	High Radiant				
adult	12.2	2.4	10	10.4	14.0
child	13.2	2.0	10	11.7	14.6
	Low Radiant				
adult	10.7	1.7	10	9.5	11.9
child	10.5	2.9	10	8.5	12.6

SWEAT HEAT LOSS INDEX ($g.hr^{-1}.W^{-1}$)

	High Radiant				
adult	1.34	.20	10	1.19	1.48
child	1.47	.28	10	1.27	1.67
	Low Radiant				
adult	1.21	.13	10	1.12	1.30
child	1.27	.23	10	1.10	1.43

APPENDIX B-15

OXYGEN UPTAKE - INCREASING METABOLISM ($ml.kg^{-1}.min^{-1}$.)

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adults	19.7	3.8	10	16.9	22.4
	child	19.5	1.3	10	18.6	20.4
10mins	adults	19.9	3.8	10	17.2	22.7
	child	18.4	2.9	10	16.4	20.5
15mins	adults	25.7	4.9	10	22.3	29.2
	child	22.4	3.4	10	19.9	24.9
20mins	adults	25.9	4.4	10	22.7	29.1
	child	23.7	3.0	10	21.5	25.9
25mins	adult	32.6	4.8	10	29.2	36.1
	child	30.7	4.7	10	27.3	34.1
30mins	adults	33.3	4.5	10	30.1	36.6
	child	30.9	4.2	10	27.8	33.9

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adults	19.9	2.4	10	18.2	21.6
	child	19.6	3.7	10	16.9	22.3
10mins	adults	20.6	2.8	10	18.7	22.6
	child	20.3	3.5	10	17.9	22.8
15mins	adults	25.2	4.2	10	22.2	28.2
	child	26.6	4.3	10	23.5	29.6
20mins	adults	26.8	3.9	10	23.9	29.6
	child	27.1	4.0	10	24.2	29.9
25mins	adults	34.1	5.3	10	30.4	37.9
	child	32.7	4.7	10	29.3	36.1
30mins	adults	34.8	5.0	10	31.2	38.3
	child	34.1	5.2	10	30.3	37.8

APPENDIX B-16

HEART RATE - INCREASING METABOLISM (b.min^{-1})

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	102	7	10	97	107
	child	122	4	10	118	125
10mins	adult	105	7	10	100	111
	child	125	7	10	121	130
15mins	adult	120	8	10	114	126
	child	140	9	10	133	146
20mins	adult	124	8	10	118	130
	child	144	10	10	137	152
25mins	adult	142	7	10	137	147
	child	161	15	10	151	172
30mins	adult	146	8	10	140	152
	child	166	17	10	154	178
	High Radiant					
5mins	adult	103	7	10	98	108
	child	122	12	10	114	131
10mins	adult	107	7	10	101	112
	child	128	12	10	119	136
15mins	adult	120	12	10	111	128
	child	147	14	10	137	157
20mins	adult	125	15	10	114	135
	child	151	15	10	150	162
25mins	adult	144	13	10	135	153
	child	169	16	10	158	181
30mins	adult	150	12	10	142	159
	child	176	16	10	164	187

APPENDIX B-17

PERCENTAGE MAXIMUM HEART RATE - INCREASING METABOLISM

Time	Status	Mean	Std.dev.	N	95%	confidence limits
	Low Radiant					
5mins	adult	54.0	3.0	10	51.9	56.2
	child	61.0	3.0	10	58.9	63.2
10mins	adult	56.1	3.4	10	53.7	58.5
	child	62.9	3.2	10	60.6	65.2
15mins	adult	63.8	4.1	10	60.9	66.8
	child	70.1	4.3	10	67.0	73.2
20mins	adult	65.9	4.0	10	63.0	68.8
	child	72.3	3.8	10	69.6	75.0
25mins	adult	75.5	4.0	10	72.6	78.3
	child	80.7	4.6	10	77.4	84.0
30mins	adult	77.8	4.3	10	74.7	80.8
	child	82.9	4.8	10	79.5	86.3
	High Radiant					
5mins	adult	54.9	3.8	10	52.1	57.6
	child	61.1	4.9	10	57.6	64.7
10mins	adult	56.8	3.9	10	54.0	59.5
	child	64.0	4.9	10	60.5	67.5
15mins	adult	63.7	6.7	10	58.9	68.6
	child	73.5	4.8	10	70.1	76.9
20mins	adult	66.3	8.1	10	60.5	72.2
	child	75.7	5.0	10	72.1	79.3
25mins	adult	76.8	7.3	10	71.6	82.1
	child	84.8	5.3	10	81.0	88.5
30mins	adult	80.1	6.9	10	75.2	85.1
	child	88.1	5.4	10	84.2	92.0

APPENDIX B-18

HEART RATE INDEX - INCREASING METABOLISM (%hr max. $\%VO_2max^{-1}$)

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	1.43	.15	10	1.32	1.55
	child	1.64	.19	10	1.51	1.78
10mins	adult	1.47	.16	10	1.36	1.59
	child	1.81	.26	10	1.63	2.00
15mins	adult	1.30	.11	10	1.21	1.38
	child	1.65	.16	10	1.53	1.77
20mins	adult	1.32	.09	10	1.26	1.38
	child	1.60	.14	10	1.51	1.70
25mins	adult	1.20	.09	10	1.14	1.26
	child	1.38	.13	10	1.29	1.48
30mins	adult	1.21	.09	10	1.14	1.27
	child	1.41	.10	10	1.34	1.49

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	1.42	.13	10	1.33	1.52
	child	1.67	.32	10	1.44	1.90
10mins	adult	1.43	.18	10	1.30	1.56
	child	1.68	.25	10	1.50	1.86
15mins	adult	1.31	.10	10	1.23	1.38
	child	1.46	.14	10	1.36	1.57
20mins	adult	1.28	.12	10	1.20	1.37
	child	1.47	.15	10	1.37	1.58
25mins	adult	1.17	.10	10	1.09	1.24
	child	1.37	.15	10	1.26	1.48
30mins	adult	1.19	.11	10	1.12	1.27
	child	1.37	.13	10	1.27	1.46

APPENDIX B-19

SKIN TEMPERATURE - NON RADIANT. INCREASING METABOLISM (°C)

Time	Status	Mean	Std.dev.	N	95%	confidence limits
	Low Radiant					
5 mins	adults	33.8	.6	10	33.3	34.3
	child	34.0	.5	10	33.7	34.5
10 mins	adults	33.3	.6	10	32.8	33.7
	child	33.9	.5	10	33.7	34.3
15 mins	adults	33.2	.7	10	32.7	33.7
	child	33.8	.6	10	33.4	34.3
20 mins	adults	33.3	.6	10	32.8	33.8
	child	33.9	.6	10	33.5	34.4
25 mins	adults	33.2	.7	10	32.7	33.8
	child	33.9	.6	10	33.4	34.3
30 mins	adults	33.3	.6	10	32.8	33.7
	child	33.9	.5	10	33.6	34.3
	High Radiant					
5 mins	adults	33.6	.9	10	32.9	34.2
	child	34.3	.5	10	33.9	34.6
10 mins	adults	33.5	.9	10	32.8	34.1
	child	34.2	.5	10	33.9	34.6
15 mins	adults	33.4	1.1	10	32.6	34.1
	child	34.3	.6	10	33.9	34.7
20 mins	adults	33.4	1.0	10	32.7	34.1
	child	34.2	.7	10	33.7	34.7
25 mins	adults	33.5	.9	10	32.8	34.1
	child	34.3	.8	10	33.7	34.8
30 mins	adults	33.4	.9	10	32.7	34.1
	child	34.5	.7	10	33.9	35.0

SKIN TEMPERATURE - EXPOSED TO RADIANT HEAT. INCREASING METABOLISM (°C)

Time	Status	Mean	Std.dev.	N	95%	confidence limits
	Low Radiant					
5mins	adult	34.8	.6	10	34.4	35.3
	child	36.0	.4	10	35.8	36.3
10mins	adult	34.6	.5	10	34.2	35.0
	child	35.8	.4	10	35.6	36.1
15mins	adult	34.5	.5	10	34.1	34.8
	child	35.7	.4	10	35.4	35.9
20mins	adult	34.5	.5	10	34.1	34.9
	child	35.7	.4	10	35.4	35.9
25mins	adult	34.5	.5	10	34.2	34.8
	child	35.5	.5	10	35.2	35.9
30mins	adult	34.5	.5	10	34.2	34.9
	child	35.5	.5	10	35.1	35.9
	High Radiant					
5mins	adult	37.9	1.1	10	37.1	28.6
	child	39.4	.6	10	39.0	39.8
10mins	adult	37.6	1.0	10	36.9	38.4
	child	39.6	.5	10	39.1	40.0
15mins	adult	37.5	.7	10	36.9	38.0
	child	39.4	.6	10	38.9	39.8
20mins	adult	37.4	.7	10	36.8	37.9
	child	39.2	.7	10	38.7	39.6
25mins	adult	37.2	.7	10	36.7	37.8
	child	39.1	.8	10	38.5	39.7
30mins	adult	37.3	.8	10	36.7	37.9
	child	39.2	.8	10	38.6	39.7

APPENDIX B-21

CORE TEMPERATURE - INCREASING METABOLISM (°C)

Low Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	37.1	.2	10	36.9	37.3
	child	37.4	.2	10	37.2	37.6
10mins	adult	37.1	.3	10	36.9	37.3
	child	37.4	.2	10	37.2	37.6
15mins	adult	37.2	.3	10	36.9	37.4
	child	37.4	.2	10	37.3	37.6
20mins	adult	37.2	.4	10	36.9	37.5
	child	37.5	.2	10	37.3	37.6
25mins	adult	37.2	.4	10	36.9	37.5
	child	37.5	.2	10	37.0	37.5
30mins	adult	37.3	.5	10	37.0	37.7
	child	37.6	.2	10	37.4	37.7

High Radiant

Time	Status	Mean	Std.dev.	N	95%	confidence limits
5mins	adult	36.9	.2	10	36.8	37.0
	child	37.3	.2	10	37.1	37.4
10mins	adult	36.9	.2	10	36.8	37.1
	child	37.3	.3	10	37.1	37.5
15mins	adult	37.0	.3	10	36.8	37.2
	child	37.4	.3	10	37.2	37.6
20mins	adult	37.1	.3	10	36.9	37.3
	child	37.5	.3	10	37.3	37.7
25mins	adult	37.2	.3	10	36.9	37.5
	child	37.6	.2	10	37.5	37.8
30mins	adult	37.3	.3	10	37.1	37.6
	child	37.8	.3	10	37.6	38.0

APPENDIX C

SPSSX ANALYSIS TABLES FOR PART A AND PART B OF THE STUDY

APPENDIX C-1

Manova for differences between the groups on the independent variables measured in part A of the study.

Surface area/mass

Source of variation	F	Sig of F
Sex (V2)	.345	.562
Status (V1)	34.844	.000
Sex by status	9.135	.005

Ponderal Index

Source of variation	F	Sig of F
Sex	.222	.641
Status	.209	.651
Sex by Status	4.857	.036

Sum of skinfolds

Source of variation	F	Sig of F
Sex	11.373	.002
Status	6.791	.015
Sex x Status	.708	.407

Maximum oxygen uptake

Source of variation	F	Sig of F
Sex	15.897	.000
Status	4.038	.055
Sex x Status	.091	.765

Heart rate maximum

Source of variation	F	Sig of F
Sex	1.143	.294
Status	3.710	.065
Sex x Status	.258	.616

Work rate

Source of variation	F	Sig of F
Sex	39.966	.000
Status	245.868	.000
Sex x Status	17.992	.000

APPENDIX C-2

Manova for differences between the groups on the dependent variables measured in part A of the study.

Average metabolism

Source of variation	F	Sig of F
Males		
Group (V1)	77.62	.000
V1 x Climate	2.30	.137
Climate	.43	.657
Females		
Group (V1)	102.42	.000
V1 x Climate	2.29	.147
Climate	1.11	.363

Average Metabolism as a percentage of VO_2 maximum

Source of variation	F	Sig of F
Total sample		
Group (V1)	7.91	.009
Sex (V2)	.31	.580
V1xV2	10.41	.003
V1xV2xClimate	.768	.474
V1xClimate	3.59	.042
V2xClimate	.203	.817
Climate	2.55	.097
Males		
Group (V1)	.14	.715
V1 x climate	2.70368	.102
Climate	1.42077	.274
Females		
Group (V1)	11.77	.005
V1 x climate	4.18346	.045
Climate	2.87012	.099
Climate 22 x V1	3.09	.104
Climate 31 x V1	13.49	.003
Climate 35 x V1	23.59	.000

Metabolic efficiency

Source of variation	F	Sig of F
Males		
Group (V1)	85.19	.000
V1 x climate	2.58350	.111
Climate	.61703	.554
Females		
Group (V1)	64.32	.000
V1 x climate	2.70107	.111
Climate	1.24209	.326

APPENDIX C-3

Manova for differences between the groups on the independent variables measured in part A of the study.

Relative heat production

Source of variation	F	Sig of F
Males		
Group (V1)	.05	.822
V1 x Climate	2.64178	.106
Climate	1.25290	.316
Females		
Group (V1)	6.33	.027
V1 x Climate	3.28213	.076
Climate	2.48402	.129
Climate 22 x V1	2.33	.155
Climate 31 x V1	13.29	.003
Climate 35 x V1	5.10	.043

Oxygen uptake

Source of variation	F	Sig of F
Males		
Group (V1)	1.85	.193
V1 x Time	2.51636	.094
Time	12.00699	.000
Climate	1.29621	.304
Climate x Time	1.06089	.493
V1 x Climate	2.67557	.104
V1 x Climate x Time	1.40775	.350
Females		
Group (V1)	10.48	.007
V1 x Climate	3.28213	.076
Climate	2.48402	.129
V1 x Time	.13655	.979
Time	2.66172	.105
V1 x Climate x Time	7.80539	.059
Climate x Time	1.09080	.533

Heart rate

Source of variation	F	sig of F
Male		
Group (V1)	31.31	.000
V1 x Climate	4.64861	.030
Climate	13.60497	.001
Time	4.43498	.022
V1 x Time	2.23437	.131
V1 x Climate x Time	2.59436	.152
Climate x Time	2.09251	.215

APPENDIX C-3 (Continued)

Heart rate (contd)

Source of variation	F	sig of F
Female		
Group (V1)	5.14	.043
V1 x Time	1.61311	.261
Time	7.37779	.007
Climate	4.48010	.038
V1 x Climate	1.00721	.397
V1 x Climate x Time	.67683	.721
Climate x Time	1.22703	.486
Climate 22°C x V1	4.39	.058
Climate 31°C x V1	2.41	.147
Climate 35°C x V1	4.61	.053

Percentage of heart rate maximum.

Source of variation	F	Sig of F
Males		
Group (V1)	43.24	.000
V1 x Climate	4.63348	.030
Climate	13.90952	.001
Time x Climate	2.15771	.205
Time	4.49036	.021
V1 x Time x Climate	2.67418	.145
V1 x Time	2.26765	.127
Climate 22°C x V1	16.84	.001
Climate 31°C x V1	18.37	.001
Climate 35°C x V1	31.00	.000
Females		
Group (V1)	2.01	.181
V1 x Time	1.68364	.244
Time	7.4927	.007
V1 x Climate	.92575	.425
Climate	4.59674	.035
V1 x Time x Climate	.75751	.678
Time x Climate	1.31442	.459
Climate 22°C x V1	1.50	.245
Climate 31°C x V1	0.72	.412
Climate 35°C x V1	3.17	.100

APPENDIX C-4

Manova for differences between the groups on the independent variables measured in part A of the study.

Heart rate index

Source of variation	F	Sig of F
Males		
Group (V1)	11.33	.005
Climate	6.05844	.014
Time	4.67843	.018
V1 x Climate	.24216	.788
V1 x Time	2.09241	.150
V1 x Climate x Time	3.00791	.118
Climate x Time	2.32710	.182
Climate 22°C x V1	3.77	.073
Climate 31°C x V1	13.00	.003
Climate 35°C x V1	7.21	.018
Females		
Group (V1)	11.33	.005
Climate	7.58683	.008
Time	7.43710	.007
V1 x Climate	1.95845	.187
V1 x Time	1.50915	.288
V1 x Climate x Time	.63245	.745
Climate x Time	1.39970	.435
Climate 22°C x V1	3.70	.079
Climate 31°C x V1	10.43	.007
Climate 35°C x V1	16.70	.002
Total sample		
Group (V1)	22.80	.000
Sex (V2)	.71	.408
V1xV2	2.00	.170
V1xV2xClimate	.34	.714
V2xClimate	.117	.890
V1xClimate	1.73	.197
Climate	13.78	.000
V1xV2xTime	.474	.791
V2xTime	.385	.853
V1xTime	2.17	.095
Time	12.18	.000
V1xV2xClimatexTime	1.28	.312
V2xClimatexTime	.748	.637
V1xClimatexTime	2.448	.050
ClimatexTime	4.489	.003

APPENDIX C-5

Manova for differences between the groups on the independent variables measured in part A of the study.

Evaporative weight loss

Source of variation	F	Sig of F
Males		
Group (V1)	58.86	.000
V1 x Climate	14.54	.000
Climate	56.28	.000
Females		
Group (V1)	20.91	.000
Climate	24.39	.000
V1 x Climate	1.80	.210

Relative evaporative weight loss

Source of variation	F	Sig of F
Males		
Group (V1)	6.97	.019
V1 x Climate	2.85	.091
Climate	58.80	.000
Climate 22 x V1	1.27	.277
Climate 31 x V1	6.14	.026
Climate 35 x V1	12.19	.003
Females		
Group (V1)	3.27	.096
V1 x Climate	.13	.453
Climate	18.17	.000

Evaporative heat loss index

Source of variation	F	Sig of F
Total sample		
Group (V1)	8.56	.007
Sex (V2)	10.36	.003
V1xV2	1.72	.201
V2xV1xClimate	.979	.389
V1xClimate	1.98	.157
V2xClimate	1.20	.316
Climate	67.17	.000
V1xClimate 22	2.38	.134
V2xClimate 22	16.30	.000
V1xV2xClimate 22	.03	.860
V1xClimate 31	1.98	.171
V2xClimate 31	8.25	.008
V1xV2xClimate	2.69	.113
V1xClimate 35	8.81	.006
V2xClimate 35	.59	.450
V1xV2xClimate 35	.86	.363

APPENDIX C-5 (contd)

Evaporative heat loss index (contd)

Source of variation	F	Sig of F
Males		
Group (V1)	9.21	.008
V1 x Climate	3.52790	.052
Climate	47.81049	.000
Climate 22 x V1	1.04	.325
Climate 31 x V1	7.81	.014
Climate 35 x V1	18.76	.001
Females		
Group (V1)	1.32	.273
V1 x Climate	.74718	.496
Climate	23.85097	.000

Mean skin temperature

Source of variation	F	Sig of F
Total sample		
Group (V1)	.91	.350
Sex (V2)	.73	.400
V1xV2	4.16	.051
V1xV2xClimate	6.83	.004
V2xClimate	.16	.846
V1xClimate	1.73	.196
Climate	814.6	.000
V1xV2xTime	1.11	.381
V2xTime	.61	.691
V1xTime	.83	.540
Time	2.41	.068
V1xV2xClimatexTime	.71	.703
V2xClimatexTime	.47	.887
V1xClimatexTime	1.39	.259
ClimatexTime	4.80	.002

Ear canal temperature

Source of variation	F	Sig of F
Total sample		
Group (V1)	18.56	.000
Sex (V2)	5.66	.026
V1xV2	.73	.401
V1xV2xClimate	1.39	.269
V2xClimate	1.64	.216
V1xClimate	1.07	.358
Climate	21.96	.000
V1xV2xTime	.29	.912
V2xTime	.82	.548
V1xTime	.54	.744
Time	2.76	.047
V1xV2xTimexClimate	1.17	.380
V2xClimatexTime	.63	.770
V1xClimatexTime	1.22	.353
ClimatexTime	6.197	.001

APPENDIX C-6

Mancova for differences between the groups on the dependent variables with SA/mass, skinfolds and VO_2 maximum being the covariates analysed in part A of the study.

Heart rate - males

Source of variation	F	Sig of F
V10 (skinfolds)regression	4.14	.063
Group (V1)	37.08	.000
V12 (SA/Mass) regression	4.02	.066
Group (V1)	1.78	.204
V15 (VO_2maximum) regression	2.84	.166
Group (V1)	37.65	.000

Evaporative heat loss index

Source of variation	F	Sig of F
Total Sample		
V10 regression	1.066	.312
Group (V1)	4.79	.038
Sex (V2)	4.62	.041
V1xV2	1.28	.268
V12 regression	.34	.564
Group (V1)	5.74	.024
Sex (V2)	10.37	.003
V1xV2	2.00	.169
V15 regression	1.08	.309
Group (V1)	5.62	.025
Sex (V2)	3.72	.065
V1xV2	1.56	.222
Males		
V10 regression	0.86	.369
Group (V1)	8.53	.011
V12 regression	0.06	.803
Group (V1)	2.05	.174
V15 regression	.01	.907
Group (V1)	6.49	.023

APPENDIX C-7

Manova for differences between the groups on the independent variables measured in part A of the study.

Core temperature

Total Sample		
V10 regression	.03	.857
Group (V1)	14.63	.001
Sex (V2)	2.98	.098
V1xV2	.59	.450
V12 regression	.37	.550
Group (V1)	5.23	.032
Sex (V2)	5.44	.029
V1xV2	.19	.667
V15 regression	1.23	.279
Group (V1)	14.25	.001
Sex (V2)	1.42	.246
V1xV2	.60	.448
V10 regression climate 22	1.06	.313
V1 x climate 22	1.26	.274
V2 x climate 22	2.16	.156
V1 x V2 x climate 22	1.72	.203
V10 regression climate 31	.01	.938
V1 x climate 31	12.64	.002
V2 x climate 31	.27	.610
V1 x V2 x climate 31	.25	.625
V10 regression climate 35	1.29	.267
V1 x climate 35	12.26	.002
V2 x climate 35	2.34	.140
V1 x V2 x climate 35	.39	.537
V12 regression climate 22	.02	.901
V1 x climate 22	1.29	.267
V2 x climate 22	6.81	.016
V1 x V2 x climate 22	2.04	.166
V12 regression climate 31	.03	.873
V1 x climate 31	6.96	.015
V2 x climate 31	.52	.478
V1 x V2 x climate 31	.12	.731
V12 regression climate 35	3.93	.060
V1 x climate 35	.56	.461
V2 x climate 35	1.13	.299
V1 x V2 x climate 35	.41	.528
V15 regression climate 22	2.41	.134
V1 x climate 22	1.28	.270
V2 x climate 22	1.42	.246
V1 x V2 x climate 22	2.33	.140

APPENDIX C-7 (Contd.)

V15 regression climate 31	.59	.450
V1 x climate 31	12.28	.002
V2 x climate 31	.01	.926
V1 x V2 x climate 31	.31	.585
V15 regression climate 35	.18	.677
V1 x climate 35	10.34	.004
V2 x climate 35	1.14	.296
V1 x V2 x climate 35	.15	.702

APPENDIX C-8

Manova for differences between the groups on the independent variables measured in part A of the study.

Heart rate index

Source of variation	F	Sig of F
Total Sample		
V10 regression	.33	.571
Group (V1)	16.68	.000
Sex (V2)	.10	.755
V1xV2	2.08	.161
V12 regression	.00	.951
Group (V1)	8.56	.007
Sex (V2)	.68	.419
V1xV2	1.38	.251
V15 regression	2.26	.145
Group (V1)	26.16	.000
Sex (V2)	2.65	.116
V1xV2	2.07	.163

Percentage of heart rate maximum - Males

Source of variation	F	Sig of F
V10 regression	5.07	.042
Group (V1)	52.10	.000
V12 regression	4.08	.064
Group (V1)	3.49	.084
V15 regression	7.91	.015
Group (V1)	72.18	.000
V1xV2	9.63	.005
V15 regression	4.32	.048
Group (V1)	0.04	.839
Sex (V2)	3.93	.058
V1xV2	4.15	.052

APPENDIX C-9

Manova for differences between the groups on the dependent variables measured under constant metabolism conditions with radiant heat.

Air temperature conditions in the chamber.

Factor	F value	Probability
Group	0.07	.789
Radiant	48.41	.000
Group x Radiant	1.37	.258
Group x Time	1.61	.229
Time	41.95	.000
Radiant x Time	7.91	.001
Group x Radiant x Time	1.09	.426

Relative humidity conditions in the chamber

Factor	F value	Probability
Group	5.18	.039
Radiant	8.33	.012
Group x Radiant	0.01	.944
Group x Time	1.35	.304
Time	16.10	.000
Radiant x Time	15.36	.000
Group x Time x Radiant	2.85	.82

Work rate of the subjects

Factor	F value	Probability
Group	150.40	.000

Oxygen uptake in the first 10 minutes

Factor	F value	Probability
Group	0.08	.777
Radiant	0.79	.388
Group x Radiant	1.73	.206
Time	0.37	.551
Group x Time	10.13	.005
Radiant x Time	0.99	.333
Group x Radiant x Time	1.39	.255

Oxygen uptake in the 30 minutes with radiant heat.

Factor	F value	Probability
Group	2.46	.135
Radiant	0.06	.806
Radiant x Group	0.21	.653
Group x Time	1.09	.407
Time	2.06	.073
Radiant x Time	1.86	.189
Group x Radiant x Time	0.95	.479

APPENDIX C-10

Manova for differences between the groups on the dependent variables measured under constant metabolism conditions with radiant heat.

Mean metabolism for the 40 minute constant metabolism test

Factor	F value	Probability
Group	179.54	.000
Radiant	0.13	.726
Group x Radiant	0.49	.495

Percentage of VO_2 maximum

Factor	F value	Probability
Group	5.68	.029
Radiant	0.03	.871
Group x Radiant	0.42	.525

Metabolic efficiency

Factor	F value	Probability
Group	76.10	.000
Radiant	0.11	.747
Group x Radiant	0.41	.531

Heat production

Factor	F value	Probability
Group	169.99	.000
Radiant	0.13	.726
Group x Radiant	0.49	.495

Relative heat production

Factor	F value	Probability
Group	.04	.842
Radiant	.000	.969
Group x Radiant	.45	.511

Sweat rate

Factor	F value	Probability
Group	87.04	.000
Radiant	17.17	.001
Group x Radiant	0.08	.779

Relative sweat rate

Factor	F value	Probability
Group	0.42	.528
Radiant	18.33	.000
Group x Radiant	0.12	.733

Sweat heat loss index

Factor	F value	Probability
Group	0.37	.553
Radiant	21.14	.000
Group x Radiant	0.00	.966

APPENDIX C-11

Manova for differences between the groups on the dependent variables measured under constant metabolism conditions with radiant heat.

Core temperature in the first 10 minutes

Factor	F value	Probability
Group	6.23	.023
Radiant	0.79	.387
Group x Radiant	0.01	.907
Time	8.61	.009
Group x Time	0.13	.718
Radiant x Time	0.97	.338
Group x Radiant x Time	0.06	.808

Core temperature for the 30 minutes with radiant heat

Factor	F value	Probability
Group	4.70	.045
Radiant	0.21	.655
Group x radiant	0.02	.888
Time	3.46	.033
Group x Time	0.75	.603
Radiant x Time	2.96	.053
Group x Radiant xTime	0.63	.676

Mean skin temperatures not exposed to radiant heat in the first 10 minutes of exercise.

Factor	F value	Probability
Group	12.16	.003
Radiant	0.42	.527
Group x Radiant	1.12	.304
Time	11.07	.004
Group x Time	0.20	.659
Radiant x Time	1.10	.309
Group x Radiant x Time	13.48	.002

Mean skin temperatures not exposed to radiant heat in the 30 minutes when radiant heat was applied to other regions

Factor	F value	P
Group	8.53	.010
Radiant	6.05	.025
Group x Radiant	3.54	.077
Group x Time	0.30	.899
Time	2.74	.066
Radiant x Time	1.14	.385
Group x Radiant x Time	1.43	.278

APPENDIX C-12

Manova for differences between the groups on the dependent variables measured under constant metabolism conditions with radiant heat.

Mean skin temperature in the first 10 minutes without radiant heat

Factor	F value	P
Group	51.93	.000
Radiant	1.22	.284
Group xRadiant	0.13	.721
Time	24.60	.000
group x Time	0.20	.663
Radiant x Time	12.87	.002
Group x Radiant x Time	0.45	.510

Mean skin temperature for the 30 minutes of exercise when it was exposed to radiant heat

Factor	F value	P
Group	43.95	.000
Radiant	375.36	.000
Group x Radiant	0.25	.693
Group x Time	3.83	.023
Time	24.40	.000
Radiant x time	4.64	.012
Group x Radiant x Time	0.28	.912

Heart rate in the first 10 minutes of exercise

Factor	F value	P
Group	24.20	.000
Radiant	5.67	.029
Group x Radiant	2.09	.167
Time	53.26	.000
Group x Time	1.28	.273
Radiant x Time	0.23	.641
Group x Radiant x Time	0.03	.859

Heart rate in the 30 minutes of exercise with radiant heat

Factor	F value	P
Group	23.38	.000
Radiant	1.64	.217
Group x Radiant	0.17	.685
Time	17.88	.000
Group x Time	1.95	.153
Radiant x Time	3.67	.027
Group x Radiant x Time	2.78	.063

APPENDIX C-13

Manova for differences between the groups on the dependent variables measured under constant metabolism conditions with radiant heat.

Percentage heart rate maximum during the 30 minutes with radiant heat

Factor	F value	P
Group	17.22	.000
Radiant	0.29	.594
Group x Radiant	0.55	.467
Time	27.95	.000
Group x time	2.55	.080
Radiant x Time	3.26	.039
Group x Radiant x Time	2.66	.070

Heart rate index during the 40 minutes of the constant metabolism test

Factor	F value	P
Group	23.82	.000
Radiant	.00	.953
Group x Radiant	.00	.988
Group x Time	3.24	.040
Time	6.27	.004
Group x radiant x time	1.73	.200
Radiant x time	1.48	.268

APPENDIX C-14

Manova for differences between the groups on the dependent variables measured under increasing metabolism conditions with radiant heat.

Air temperature in the climate chamber

Factor	F value	P
Group	0.40	.533
Radiant	82.99	.000
Group x Radiant	0.05	.830
Group x Time	1.20	.355
Time	27.33	.000
Radiant x Time	21.91	.000
Group x Radiant x Time	0.97	.464

Relative humidity in the climate chamber

Factor	F value	P
Group	19.55	.000
Radiant	20.39	.000
Group x Radiant	1.20	.289
Time	13.93	.000
Group x Time	4.72	.024
Radiant x Time	10.94	.001
Group x Radiant x Time	7.85	.004

Work rates for the increasing metabolism test.

Factor	F value	P
Group	113.64	.000
Radiant	1.03	.324
Group x Radiant	0.03	.864
Time	325.21	.000
Group x Time	66.73	.000
Radiant x Time	0.94	.408
Group x Radiant x Time	0.94	.408

Oxygen uptake over the 30 minutes of the increasing metabolism test.

Factor	F value	P
Group	0.44	.517
Radiant	18.53	.000
Group x Radiant	46.2	.028
Time	163.36	.000
Group x Time	0.19	.957
Radiant x Time	1.93	.153
Group x Radiant x Time	5.01	.008

APPENDIX C-15

Manova for differences between the groups on the dependent variables measured under constant metabolism conditions with radiant heat.

Average metabolism for the 3 levels of the increasing metabolism test

Factor	F value	P
Group	153.99	.000
Radiant	14.50	.001
Group x Radiant	1.10	.308
Level	342.28	.000
Group x Level	48.12	.000
Radiant x Level	1.20	.324
Group x radiant x Level	6.71	.007

Percentage of maximum oxygen uptake for each level of the increasing metabolism test.

Factor	F value	P
Group	2.68	.121
Radiant	16.88	.001
Group x Radiant	4.24	.054
Level	628.28	.000
Group x Level	1.29	.300
Radiant x Level	3.22	.065
Group x Radiant x Level	8.66	.003

Metabolic efficiency for each level of the increasing metabolism test.

Factor	F value	P
Group	72.77	.000
Radiant	11.46	.003
Group x Radiant	2.40	.139
Level	37.06	.000
Group x Level	3.32	.060
Radiant x Level	0.65	.531
Group x Radiant x Level	4.54	.025

Heat production at the three levels of the increasing metabolism test.

Factor	F value	P
Group	146.85	.000
Radiant	13.97	.002
Group x Radiant	1.12	.304
Level	264.64	.000
Group x Level	33.41	.000
Radiant x Level	1.08	.359
Group x Radiant x Level	6.66	.007

APPENDIX C-16

Manova for differences between the groups on the dependent variables measured under constant metabolism conditions with radiant heat.

Relative heat production at the three levels of the increasing metabolism test

Factor	F value	P
Group	0.38	.564
Radiant	18.20	.000
Group x Radiant	5.75	.028
Level	205.92	.000
Group x Level	0.08	.923
Radiant x Level	3.10	.071
Group x Radiant x Level	8.10	.003

Sweat rate for the increasing metabolism tests

Factor	F value	P
Group	87.04	.000
Radiant	17.17	.001
Group x Radiant	0.08	.779

Relative sweat rate for the increasing metabolism tests.

Factor	F value	P
Group	.020	.662
Radiant	21.59	.000
Group x Radiant	1.54	.230

Sweat heat loss index in the increasing metabolism tests.

Factor	F value	P
Group	1.45	.244
Radiant	8.84	.008
Group x Radiant	0.44	.516

Core temperature for the increasing metabolism test.

Factor	F value	P
Group	9.09	.007
Radiant	0.84	.372
Group x Radiant	1.42	.248
Time	11.89	.000
Group x Time	0.23	.941
Radiant x Time	3.91	.020
Group x Radiant x Time	1.35	.298

APPENDIX C-16 (Contd.)

Mean skin temperature not exposed to radiant heat during the increasing metabolism test.

Factor	F value	P
Group	7.21	.015
Radiant	2.72	.070
Group x Radiant	0.78	.339
Time	3.19	.039
linear	0.73	.403
Quadratic	11.59	.003
Group x Time	0.81	.559
Radiant x Time	3.34	.034
Group x Radiant x Time	1.97	.145

APPENDIX C-17

Manova for differences between the groups on the dependent variables measured under constant metabolism conditions with radiant heat.

Mean skin temperature exposed to radiant heat during the the increasing metabolism test

Factor	F value	P
Group	47.96	.000
Radiant	538.92	.000
Group x Radiant	6.22	.023
Time	2.23	.108
Group x Time	2.54	.077
Radiant x Time	1.32	.309
Group x Radiant x Time	0.91	.497

Heart rate during the increasing metabolism tests

Factor	F value	P
Group	30.57	.000
Radiant	4.10	.058
Group x Radiant	1.24	.280
Time	67.3	.000
Group x Time	0.90	.505
Radiant x Time	1.07	.414
Group x Radiant x Time	1.17	.370

Percentage of maximum heart rate during the the increasing metabolism test.

Factor	F value	P
Group	22.43	.000
Radiant	4.04	.060
Group x Radiant	1.03	.323
Time	79.11	.000
Group x Time	0.72	.617
Radiant x Time	1.21	.355
Group x Radiant x Time	1.16	.374

Heart rate index during the increasing metabolism test with radiant heat.

Factor	F value	P
Group	20.67	.000
Radiant	6.57	.020
Group x radiant	2.12	.162
Group x time	1.07	.419
Time	29.43	.000
Group x radiant x time	3.07	.044
Radiant x time	1.99	.141

APPENDIX C-18

Manova for differences between the groups on the dependent variables with SA/mass being the covariate analysed in part B of the study.

Core temperature - constant metabolism

Source of variation	F	Sig of F
Regression 10 mins	1.38	.257
Group	14.51	.050
Regression 30 mins	.08	.777
Group	1.31	.270

Skin temperature exposed to radiant heat - constant metabolism

Source of variation	F	Sig of F
Regression 10 mins	6.61	.020
Group	1.30	.271
Regression 30 mins	.04	.852
Group	6.36	.023

Skin temperature not exposed to radiant heat - constant metabolism

Source of variation	F	Sig of F
Regression 10 mins	.04	.839
Group	1.51	.237
Regression 30 mins	.04	.840
Group	1.88	.189

Percentage heart rate maximum -constant metabolism

Source of variation	F	Sig of F
Regression 10 mins	0.47	.501
Group	1.33	.266
Regression 30 mins	0.91	.354
Group	.58	.459

Core temperature - increasing metabolism

Source of variation	F	Sig of F
Regression 0-10 mins	.28	.601
Group	1.00	.331

Skin temperature exposed to radiant heat - increasing metabolism

Source of variation	F	Sig of F
Regression 0-10 mins	1.48	.240
Group	1.67	.213

Skin temperature not exposed to radiant heat - increasing metabolism

Source of variation	F	Sig of F
Regression 0-10 mins	2.92	.106
Group	.22	.641

Percentage of heart rate maximum - increasing metabolism

Source of variation	F	Sig of F
Regression 0-10 mins	1.09	.312
Group	1.82	.195